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BULLETIN
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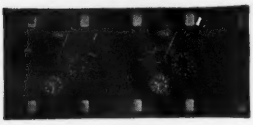

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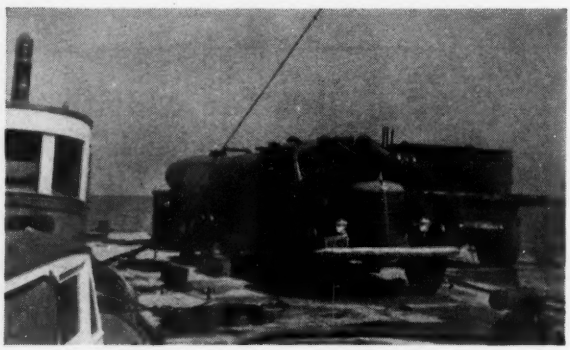

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OIL AND GAS WELL CHEMICAL SERVICE

Volume 25 Number 2

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

FEBRUARY, 1941

MIOCENE OF CALIENTE RANGE AND ENVIRONS, CALIFORNIA[1]

J. E. EATON,[2] U. S. GRANT,[3] AND H. B. ALLEN[4]
Los Angeles, California

ABSTRACT

Caliente Range and environs furnishes what is believed to be the best Miocene record for California. Approximately 180 molluscan and echinoderm faunas representing 47 nearly consecutive horizons from that of *Turritella inezana* var. *hoffmani* upward to well above that of *Astrodapsis tumidus* have been obtained from a Miocene succession locally about 13,800 feet in thickness. At Caliente Mountain a homoclinal section exposes, upward, successively about 1,100 feet of upper Oligocene(?), 4,500 feet of Vaqueros (lower Miocene), 4,700 feet of Temblor (middle Miocene), and 4,600 feet of Monterey (upper Miocene) strata. The marine Miocene series locally grades on the one hand to fine facies yielding foraminifers, and on the other to coarse continental facies yielding terrestrial vertebrates. The district lies at the junction of the three largest Miocene provinces of the state, linking their histories.

The area discussed formed the pivotal part of a peculiarly long, narrow, and deep upper Oligocene and Miocene trough about 300 miles in length and 20 in width which seemingly extended from the Santa Cruz region southeast to Caliente Range. At this latter place the trough forked, sending a branch east into what is now the San Emigdio foothill region of southern San Joaquin Basin, with the original strike continuing southeast to intersect and die out in Ventura Basin. A thick marine succession along the axis of the trough grades on the flanks to thin wedges separated by unconformities that appear and grow strandward. Near its heads the succession locally passes into continental deposits with similar areal relations.

The trough was pinched out and strongly deformed and eroded by post-Miocene diastrophism. Its strata were steeply tilted, locally overturned and overthrust, and in places largely removed. Thrusts, erosion, slides, and alluvial débris have obliterated or hidden stretches near its mouth, both heads, and intermittently between these points.

Evidence secured in Caliente Range and environs, in combination with state-wide data, suggests the following history. In the lower Oligocene California seems to have been completely emergent, with continental deposits being locally laid down near the present coast. In the upper Oligocene the sea invaded the state as a narrow inlet occupying the newly initiated Caliente trough, continental deposition continuing in most former areas of that nature. The marine Miocene of California is a transgressive series, essentially conformable basinward, but revealing, strandward, the occurrence of two oscillations which respectively inaugurate and divide its upper third. It comprises three

[1] Presented by title by the senior writer before the Pacific Section of the Association, Los Angeles, November 7–8, 1935. Manuscript received, August 12, 1940.

[2] Consulting gelogist, 2062 North Sycamore Avenue.

[3] Professor, department of geology, University of California at Los Angeles.

[4] Graduate student, University of California at Los Angeles.

nearly equal major natural divisions, the Vaqueros, Temblor, and Monterey stages, which approximate lower, middle, and upper Miocene. Each of these has a more or less distinctive epeirogenic history, fauna, and average physical aspect.

The sea transgressed throughout the Vaqueros stage, hesitated without receding, and then advanced more widely during the Temblor. Moderate regression accompanying diastrophism of locally prominent to locally imperceptible intensity and a widespread quickening of vulcanism then caused strandward unconformity. In early lower Monterey (Briones) time the sea again advanced widely. Its boundaries remained more or less static during the late lower Monterey (Cierbo). Moderate regression and diastrophism then again caused strandward unconformity. In upper Monterey (Neroly) time the sea once more advanced, reaching its widest extent during the epoch. The Miocene series records progressively cooler waters, the tropical Vaqueros fauna giving way to the subtropical fauna of the Temblor, and this in turn to the slightly hardier fauna of the Monterey. Each fauna changed relatively slowly during its stage, with hardier forms of the succeeding dynasty encroaching as an admixture in open, cooler waters, and then gave way to a new fauna with relative rapidity during a short transitional interval corresponding to one of the epeirogenic movements that divide the Miocene series of California into approximately equal thirds as regards major physical and coincident faunal units.

Wide regression resulting in almost or quite complete emergence of California separates the Miocene series from the markedly different and more restricted Pliocene series.

ACKNOWLEDGMENT

Notes on the geology of Cuyama Valley were published by Antisell[5] in 1857, and on a diabase exposure in this valley by Fairbanks[6] in 1895. Arnold and Johnson[7] made a reconnaissance of northwestern Carrizo Plain in 1910. In 1916 English[8] published a report on Cuyama Valley, and included portions of the southwestern slope of Caliente Range. In 1936 Reed and Hollister[9] discussed some features and relations of the district as a whole. A paper by Eaton[10] in 1939 summarized data set forth in more detail in the current treatise.

The present writers are indebted to T. C. I. Anderson, B. L. Clark, W. H. Corey, L. G. Hertlein, E. M. Irving, Myra Keen, G. A. MacDonald, E. H. Quayle, H. G. Schenck, G. Y. Wheatley, W. P. Woodring, and Dorothea Woodworth for assistance during the progress of the work, and to P. P. Goudkoff, D. D. Hughes, R. M. Kleinpell, Boris Laiming, and W. D. Rankin for the determination of

[5] Thomas Antisell, *in* "Pacific Railroad Reports," *U. S. War Dept.*, Vol. 7, Pt.2 (1857), pp. 53–57.

[6] H. W. Fairbanks, "Analcite Diabase in San Luis Obispo County, California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 1, No. 9 (1895), pp. 273–300.

[7] Ralph Arnold and H. R. Johnson, "McKittrick-Sunset Oil Region, California," *U. S. Geol. Survey Bull. 406* (1910), pp. 73, 202–03.

[8] W. A. English, "Geology and Oil Prospects of Cuyama Valley, California," *U. S. Geol. Survey Bull. 621-M* (1916).

[9] R. D. Reed and J. S. Hollister, *Structural Evolution of Southern California* (Amer. Assoc. Petrol. Geol., 1936), pp. 75–85.

[10] J. E. Eaton, "Geology and Oil Possibilities of Caliente Range, Cuyama Valley, and Carrizo Plain, California," *California Jour. Mines and Geol.*, Vol. 35, No. 3 (July, (1939) pp. 255–74.

foraminiferal faunas. J. S. Dougherty and Chester Stock have contributed information on the terrestrial mammals. W. F. Barbat, Alex Clark, H. S. Gale, A. I. Gregersen, J. S. Hollister, and R. D. Reed supplied various data. Headquarters and other assistance were furnished by H. P. Wells and family in Carrizo Plain, and by Mrs. F. M. Richardson and Mr. and Mrs. A. W. Jones in Cuyama Valley.

REGIONAL RELATIONS

Figure 1 presents paleogeographic maps of middle and southern California showing the relation of the district particularly discussed to some regional features in the Oligocene and Miocene. The mapping shows relations subsequent to pressure directed southwest that has narrowed the state; during the times illustrated most sea and land areas southwest of the San Andreas rift were about half again as wide as these are drawn, and areas northeast of and adjacent to this rift were also wider in varying degree. The trace of the San Andreas and Garlock rifts are shown as these exist at present, after pressure directed southwest has bent their originally straighter courses into pronounced arcs. Basins crossing the San Andreas rift are shown in their present relations after being horizontally offset by movement along this rift.

Physical and faunal unities.—The transgression in California through Oligocene and Miocene time appears to have been essentially progressive except for two moderate oscillations: one between the Temblor and Monterey stages, and one between the Cierbo and Neroly substages of the Monterey, which caused strandward unconformity. Successive advances of the Miocene sea were in general each wider than the preceding advance. The general transgression took place as a result of a series of epeirogenic pulsations, between each two of which the advance was relatively slow. The Vaqueros, Temblor, and Monterey stages were each inaugurated by an epeirogenic surge or acceleration of transgression that quickly brought wider, slightly cooler waters and a new major fauna; advance and faunal change then progressed relatively slowly until another major surge brought a wider sea, cooler waters, accelerated evolution and biologic readjustment, and the distinctive fauna of another major stage. Each stage, in turn, is divided into substages by lesser epeirogenic changes in acceleration with their lesser changes in fauna, these latter being less obvious, but recognizable from perceptible changes in acceleration with coincident changes in fauna such as those between the lower and upper Vaqueros (Fig. 1), and between the Briones, Cierbo, and Neroly substages of the Monterey (Fig. 8).

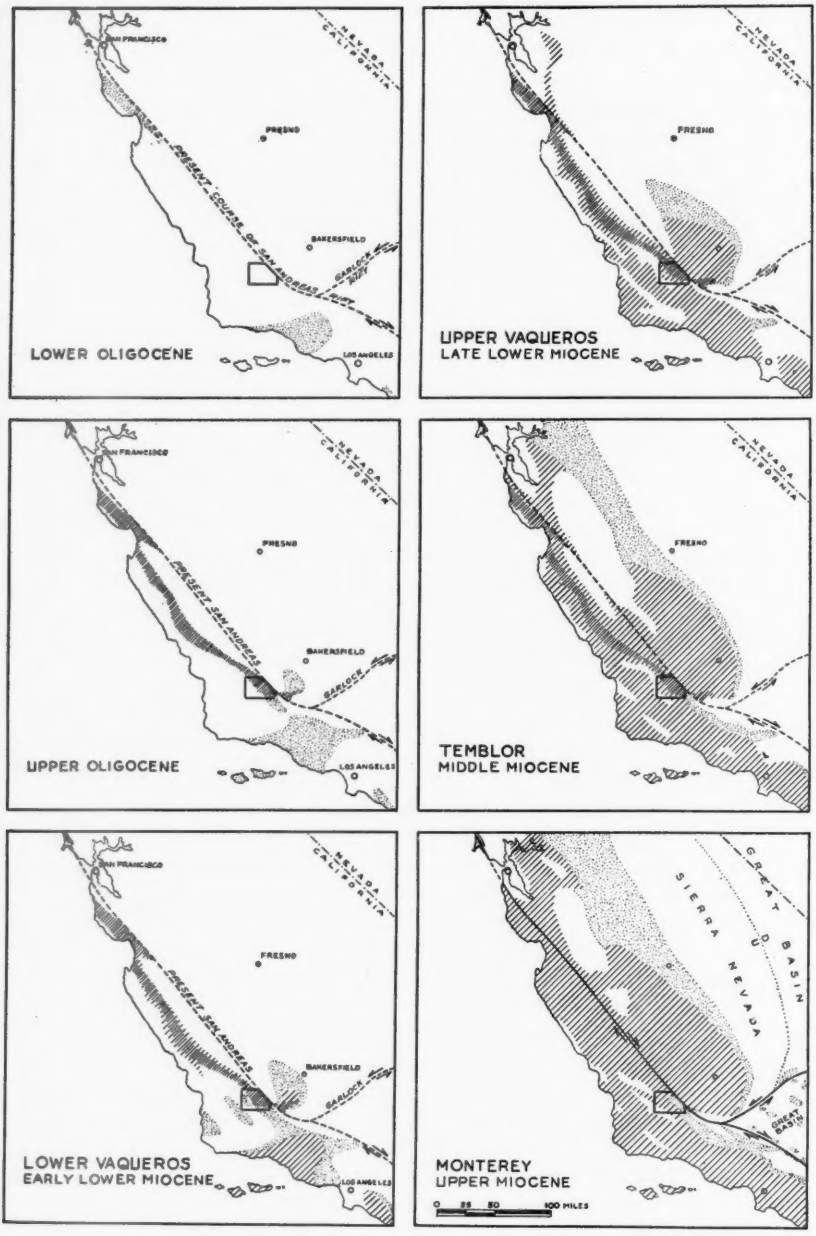

FIG. 1.—Marine deposition, lined; Caliente trough, close-lined; non-marine deposition, stippled. Area particularly discussed shown in heavy outline. Proportions as of to-day, after extreme transverse shortening and horizontal offsetting; major rift faults as of to-day, after their relatively straight original courses have been bent into pronounced arcs.

As a generalization from observed regional phenomena, marine Miocene sediments of California tend, on the average, to be of prevailingly coarse, medium, or fine grain according to whether they were laid down respectively from about 0 to 20, 20 to 35, or 35 plus miles from a *mainland*. An average is specified because there is large and erratic variation from these figures according to differing local conditions. A rough generalization seems to hold for the relation to rugged islands and peninsulas, but the distances must be halved, quartered, and so on according to the indicated size and relief of these other lands. That a vertically coarse or fine averaged texture tends to be merely a local facies at one point in an everchanging areal gradation from gravel to clay, and is of little significance if its relation to sources is undetermined, has not been sufficiently stressed in California, though Louderback[11] early called attention to evidence of the principle involved. There is a tendency to think of the Vaqueros as having been a time of universal sand, the Temblor of alternate sand and shale, and the Monterey of universal shale deposition because their types (which are merely local facies) happen to be respectively of these textures due to Miocene transgression having caused the facies of successive Miocene stages exposed in the Coast Ranges to represent sedimentation which as an average was progressivly more distant from a mainland. Yet at similar distances from its mainland each stage tends to be represented by sediments of somewhat similar texture.

The Caliente Range district, shown on Figure 1 in heavy outline, was so connected with various seas as to reflect changes in deposition and fauna, yet was also related to persistent local lands in such a manner that this small area could duplicate, almost throughout the Miocene, an extreme range of physcial and faunal facies whose record elsewhere in the state is shifting and scattered.

Regional sequence.—Wide emergence of California in the Oligocene, resulting in general unconformity between the Eocene and Miocene series, was recognized by early workers. Small areas of marine Oligocene were found, however, lying with apparent conformity below lower Miocene Vaqueros near the mouth and head of Caliente trough, and other areas are now indicated to occur at intervals along a line between these points, suggesting that a narrow finger of the sea locally pierced the state in the upper Oligocene (Fig. 1). It has long been held that the thick, continental Sespe sequence of Southern California probably includes a terrestrial record of the entire Oligo-

[11] G. D. Louderback, "The Monterey Series in California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 7, No. 10 (1913), pp. 177–241.

cene epoch, a conclusion which terrestrial vertebrate faunas (lately secured) and their relation to underlying Eocene and overlying Miocene marine invertebrate faunas are tending to verify. From time to time interpretations which would extend marine Oligocene beyond the narrow Caliente trough have been advanced and abandoned. The latest of these is that the so-called *Turritella variata* or *Uvigerina cocoaensis* zone may be Oligocene instead of Eocene. Such an assignment is doubtful, since Woodring[12] has considered this zone to be upper Eocene on the basis of its megafauna, Kleinpell[13] has called attention to its foraminiferal affinity with the Jackson (Eocene) of the Gulf Coast, and it has been generally reported to lie conformably on the Tejon (Eocene) and unconformably below the Vaqueros (lower Miocene). In summary, marine Oligocene in California is for the present viewed as being almost confined to the narrow Caliente trough, with a probably complete continental series being included in the thick Sespe succession of the south. A widespread unconformity apparently represents the epoch elsewhere in the state.

The Miocene is represented by the great transgressive series illustrated in Figure 1. The Vaqueros stage (lower Miocene), though comprising as a whole one natural unit, is divisible into a lower and an upper substage by a minor but usually perceptible change in the fauna that coincided with an acceleration of transgression about the middle of Vaqueros time. The tropical Vaqueros may be zoned on various species and assemblages, as Loel and Corey[14] have indicated. One useful criterion is the successive appearance of varieties of *Turritella inezana*. Although the ranges of these varieties overlap, they furnish, together with a few other guides, the bulk of the specimens, and what is perhaps the most useful means of checking positions in the sequence.

The oldest marine strata of Vaqueros age are known only from Caliente trough, the earliest guide form, *Turritella inezana* var. *hoffmani*, having been reported only from basal beds near the mouth and head of this trough. In Southern California this oldest horizon is seemingly represented by the *Promerycochoerus?*[15] and perhaps by the

[12] W. P. Woodring, "Age of the Orbitoid-Bearing Eocene Limestone and Turritella Variata Zone of the Western Santa Ynez Range, California," *Trans. San Diego Soc. Nat. History*, Vol. 6, No. 25 (1931), pp. 371–88.

[13] R. M. Kleinpell, *Miocene Stratigraphy of California* (Amer. Assoc. Petrol. Geol., 1938), pp. 102 and 177.

[14] Wayne Loel and W. H. Corey, "The Vaqueros Formation, Lower Miocene of California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 22, No. 3 (1932). See range charts, pp. 136–38.

[15] Chester Stock, "Oreodonts from the Sespe Deposits of South Mountain, Ventura County, California," *Carnegie Inst. Washington Pub. 404* (1930), pp. 27–41.

subjacent *Miohippus* beds of the continental upper Sespe, and in the San Emigdio Mountains by *Promerycochoerus* and *Hypertragulus* in the continental Tecuya. Late lower Vaqueros marine strata with *T. inezana* var. *bicarina*, *T. inezana* var. *sespeensis*, *Rapana vaquerosensis* s.s., *et cetera*, are more widespread, being also known from the Ventura and Los Angeles basins where they grade down conformably into continental upper Sespe that is apparently equivalent to the early lower Vaqueros.

In upper Vaqueros time the sea transgressed more widely. *Turritella inezana* s.s. and *Lyropecten magnolia* were now dominant. Short-ranged species and varieties appearing upward, such as *Ostrea vaquerosensis* in the late upper, and *T. inezana* var. *altacorona* in the uppermost Vaqueros, allow the upper Vaqueros substage to be zoned rather closely. A few relatively hardy species of the succeeding Temblor stage, notably *T. ocoyana* and *Echinarachinus norrisi*, locally appeared in the more open, cooler waters where they existed as an admixture with upper Vaqueros index fossils such as those mentioned.

At the inception of the Temblor stage the sea transgressed much more widely and rapidly (Fig. 1), bringing a slightly cooler, subtropical fauna, and eliminating somewhat abruptly tropical Vaqueros guides. The abundant Temblor fauna of California has not as yet been monographed, and collections by the writers from Caliente Range are incomplete. The stage is therefore illustrated as a whole, though future work will presumably warrant the recognition of two or three thick substages. A number of rather precise zones have been established within the Temblor by foraminiferal workers, but more study, both megafaunal and microfaunal, is needed on homotaxial features which are present due to areally different ecologies.

Diastrophism accompanied by a marked increase in vulcanism began late in Temblor time. Culminating at the close of this stage, it caused a partial regression of the sea (not shown in Fig. 1) between the Temblor and the Monterey that reduced the extent of marine waters to approximately that shown for the upper Vaqueros, though not necessarily with exactly the same boundaries, resulting in strandward unconformity but basinward conformity.

At the beginning of the Monterey stage the sea again advanced. Slightly cooler waters eliminated much of the subtropical Temblor fauna, and established a less subtropical Monterey fauna that had been encroaching during the prior, transitional period of regression. The Monterey comprises or includes three named substages: reading upward, the Briones, Cierbo, and Neroly, which appear to be conformable basinward but the two latter of which are locally separated

strandward by an unconformity. These substages can be recognized strandward by distinctive echinoderm faunas, and by a number of more or less distinctive mollusks. Transgression in the Briones substage was followed by somewhat static seas in the Cierbo. Moderate regression, diastrophism, and strandward unconformity then occurred. During the Neroly the sea once more advanced, attaining, in this substage, its maximum extent during the Miocene.

At the close of Monterey time the sea almost or quite receded from California, resulting in widespread unconformity that separates the Miocene series from the equally thick but markedly different and areally more restricted superjacent Pliocene series.

STRUCTURAL HISTORY

The district particularly discussed (heavy outline in Fig. 1) seems to reveal no evidence for a trough in Cretaceous and Eocene times. It was apparently only a part of the wide area of Cretaceous deposition, and beds of definite Eocene age, though these bound Cuyama Valley on the southeast and possibly occur beneath parts of this valley at depth, have so far not been located here. The feature that the lower Miocene rests depositionally on the Cretaceous(?) over wide areas with a discordance of 30°–50° in dip, and as much in strike, suggests that during parts of the missing record the district was a positive area lying between negative areas on the northeast and southwest.

In or about middle Oligocene time the foregoing structural relation was reversed. The district then became the pivotal part of a long, narrow trough or graben (double-ruled in Fig. 1) which entered it from the northwest, and, forking where Caliente Range now stands, sent a branch almost due east through the San Emigdio district. The circumstance that in the central channel of the trough the Oligocene(?) and lower Miocene strata are persistently marine, whereas equivalent beds which bound the trough on the south and west are non-marine, favors a northwest connection with the sea. Such a course can be traced, intermittently, northwest to the type locality of the San Lorenzo north of Monterey Bay, but the record is fragmental between King City and that district due to alluvium and profound post-Miocene deformation and erosion. In this latter, dimmer stretch, the occurrence of isolated patches of the older Miocene faulted down between igneous and metamorphic masses suggests that during much or all of the Miocene the Caliente trough struck northwesterly to the sea. The persistence of such a long, straight, and deep trench throughout Miocene time seems unexplainable except by a persistently active parent fault.

Caliente trough is structurally somewhat similar to the much younger Priest Valley trough of Pliocene and lower Pleistocene time, suggesting that the mechanics of both may have been similar. The latter trough parallels the northeast side of Reed's Salinia,[16] and the former the southwest side, the crystalline nature of this granitic backbone being favorable for the occurrence of long, narrow grabens.

Throughout upper Oligocene(?) and all of Miocene time the Caliente trough remained persistently a marine area. The San Emigdio region east of Caliente Range, and the La Panza, southwestern Salinas Valley, and Monterey-Santa Cruz areas northwest of this range were then apparently parts of one narrow channel. All have a somewhat similar upper Oligocene(?) and Miocene marine succession. The thickest and most persistently fossiliferous Miocene sediments occur in the extremely depressed Caliente Range portion of the trough, near its fork.

In the upper Oligocene(?) and very earliest Miocene the Caliente trough (Santa Cruz district to the San Emigdio foothills) seems to have been the only marine inlet deeply penetrating what is now California. During the Vaqueros stage the marine waters transgressed farther, resulting in a network of waterways and additional inlets, and causing parts of the trough to become only a more rapidly subsiding portion of wider seas during the balance of Vaqueros, and all of Temblor and Monterey time. The axial part resisted the regression at the close of the Temblor, thus acquiring a thousand or so feet of Temblor-Monterey transition strata which are locally absent elsewhere. Abnormal subsidence of the particular district ended after the *Valvulineria californica* zone sequence was deposited, this zone being only about twice average, and all subsequent zones of slightly less than average, thickness for the state. At the close of the Miocene the particular district became emergent, and, except for some non-marine deposition of Pliocene(?) and late Pleistocene age, has remained so to the present, undergoing extreme deformation and deep erosion.

LOCAL RELATIONS

Figure 2 illustrates some average relations for the Miocene at Caliente Range and environs.

Relative subsidence and thickness.—The local center and much of the local southwest flank of Caliente trough are exposed in the district; the northeast flank is in part exposed, sufficient to indicate that it extended at least as far as the present line of the San Andreas rift (Fig. 3).

[16] R. D. Reed, *Geology of California* (Amer. Assoc. Petrol. Geol., 1933).
R. D. Reed and J. S. Hollister, *op. cit.*

During the earlier work the writers were inclined to believe that the axis for maximum subsidence and thickness in the Miocene coincided approximately with that of the present Wells Ranch syncline; that this large syncline is a residual feature representing a persisting of the original axis. Sections subsequently made across the northwest and southeast ends of Caliente Range indicate, however, that during the older Miocene the axis for maximum subsidence and thickness was farther southwest, approximately along what is now the crest of Caliente Range, and the axis is so drawn in Figure 2. The main axis apparently migrated northeastward with time. The position drawn is that calculated for the Vaqueros. The axis seems to have shifted northeast about one mile for each succeeding stage, with the result that the axis of the Wells Ranch syncline does presumably approximate the position in the Pliocene(?), and may thus be residual. The axis during deposition plunged from both ends toward a point located a little east of Caliente Peak. The thickest section in the basin intersects this point.

Relative texture.—The feature that as an average more than 90 per cent of the materials came from the northeast, and less than 10 per cent from the southwest, caused the axis for finest textures to lie far southwest of that for maximum subsidence and thickness, near the southwestern edge of the basin. The Miocene sediments grade southwesterly from coarse and largely continental near the San Andreas rift to relatively fine and almost wholly marine along the axis for finest textures, crossing the axis for maximum subsidence and thickness without being perceptibly influenced by this, though detailed work would presumably reveal changes in rate of gradation due to local differences in cubic capacity. Southwest of the axis for finest textures the sediments grade back to coarse facies toward the southwestern strand, this gradation being more rapid due to the relative narrowness of the southwestern flank.

Progressive gradation across the intervening structural axis resulted from the enormous supply of materials derived from the northeast, which caused adequate sedimentation to prevail, under control of the profile of equilibrium, over most of the district. As an average for the Miocene, traction-laid sediments prevail over the region except in a relatively small area which approximates the shaded area on Figure 2 labelled "foraminiferal optimum in Temblor and Monterey," where, as an average, inadequate sedimentation from suspension and solution prevailed, and the profile of equilibrium was apparently not the dominant control. An average is specified because during certain times wedges of fine sediment were laid down strandward to or beyond

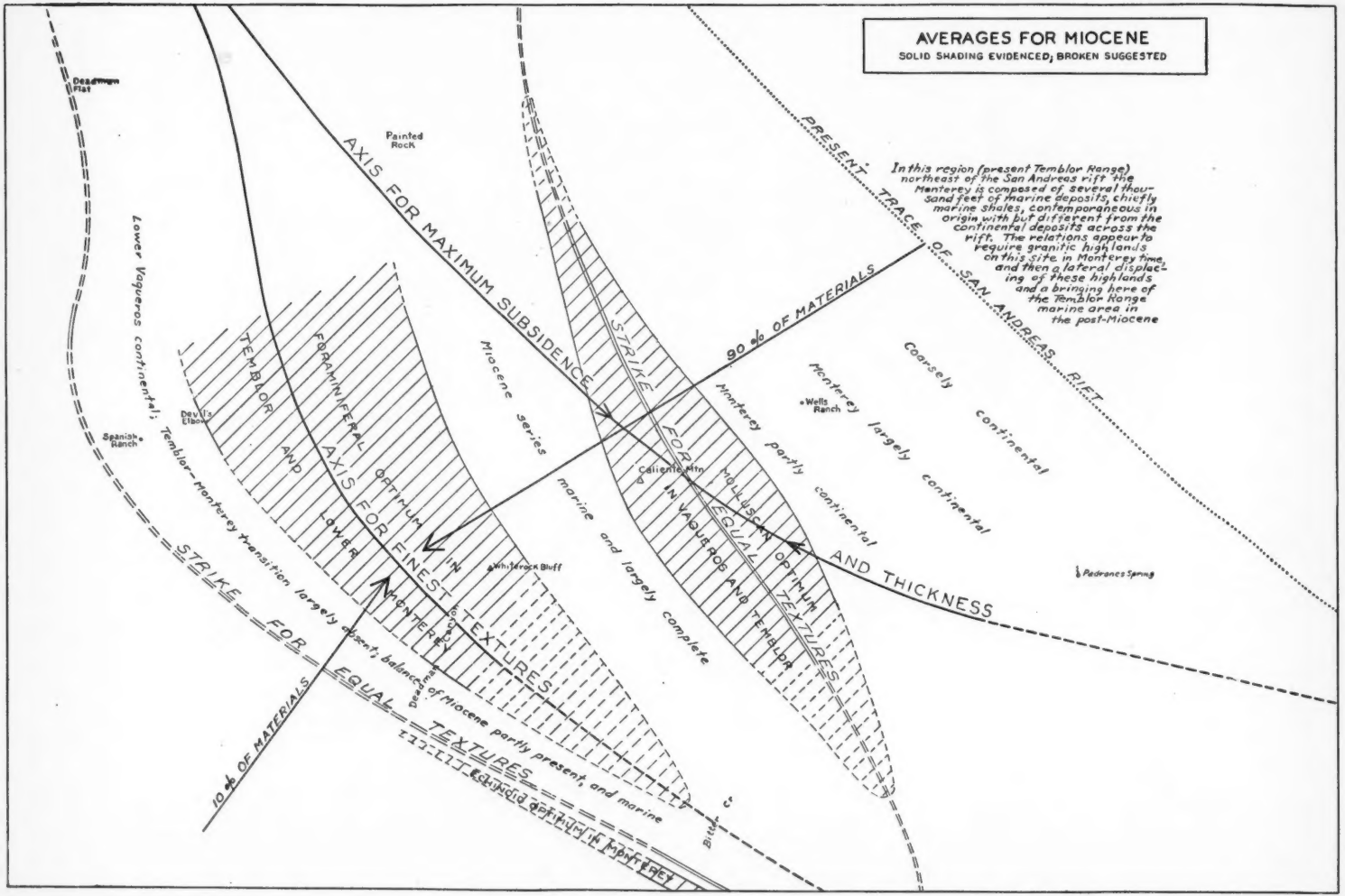
AVERAGES FOR MIOCENE
SOLID SHADING EVIDENCED; BROKEN SUGGESTED
Deadman Flat
Painted Rock
AXIS FOR MAXIMUM SUBSIDENCE
PRESENT TRACE OF SAN ANDREAS RIFT
In this region (present Temblor Range) northeast of the San Andreas rift the Monterey is composed of several thousand feet of marine deposits, chiefly marine shales, contemporaneous in origin with but different from the continental deposits across the rift. The relations appear to require granitic highlands on this site in Monterey time, and then a lateral displacing of these highlands and a bringing here of the Temblor Range marine area in the post-Miocene
90 % OF MATERIALS
Lower Vaqueros continental; Temblor-Monterey transition largely absent; balance of Miocene partly present, and marine
Miocene series
Coarsely continental
Monterey largely continental
Monterey partly continental
Wells Ranch
Devil's Elbow
Spanish Ranch
Caliente Mtn.
STRIKE FOR EQUAL OPTIMUM TEXTURES IN VAQUEROS AND TEMBLOR
FORAMINIFERAL AXIS FOR FINEST TEXTURES
TEMBLOR AND LOWER MONTEREY
AXIS FOR OPTIMUM IN MOLLUSCAN EQUAL TEXTURES
marine and largely complete
Whiterock Bluff
Pedrones Spring
AND THICKNESS
10 % OF MATERIALS
STRIKE FOR EQUAL TEXTURES
Buttonwillow

FIG. 2

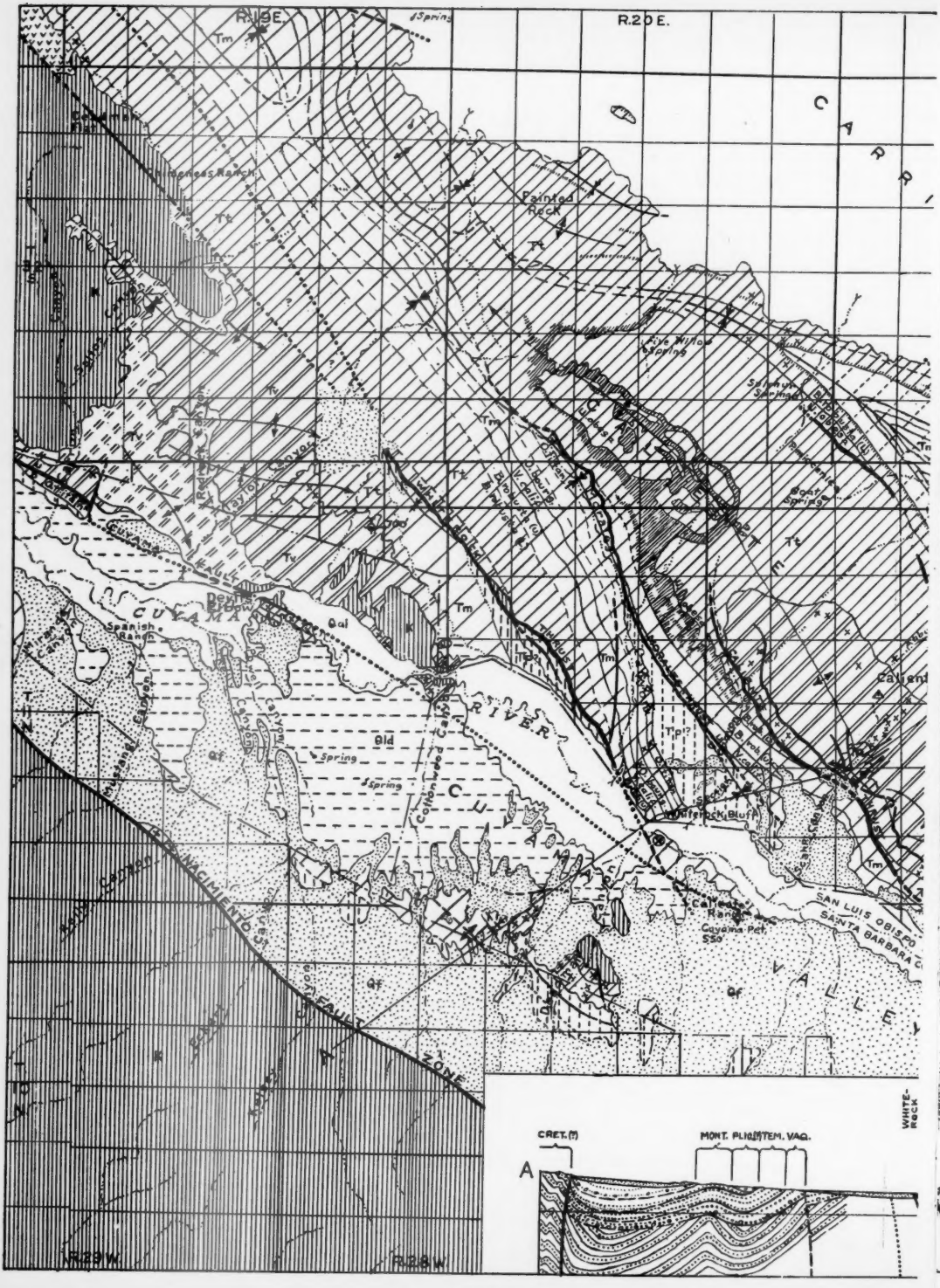

FIG. 3 (west half)

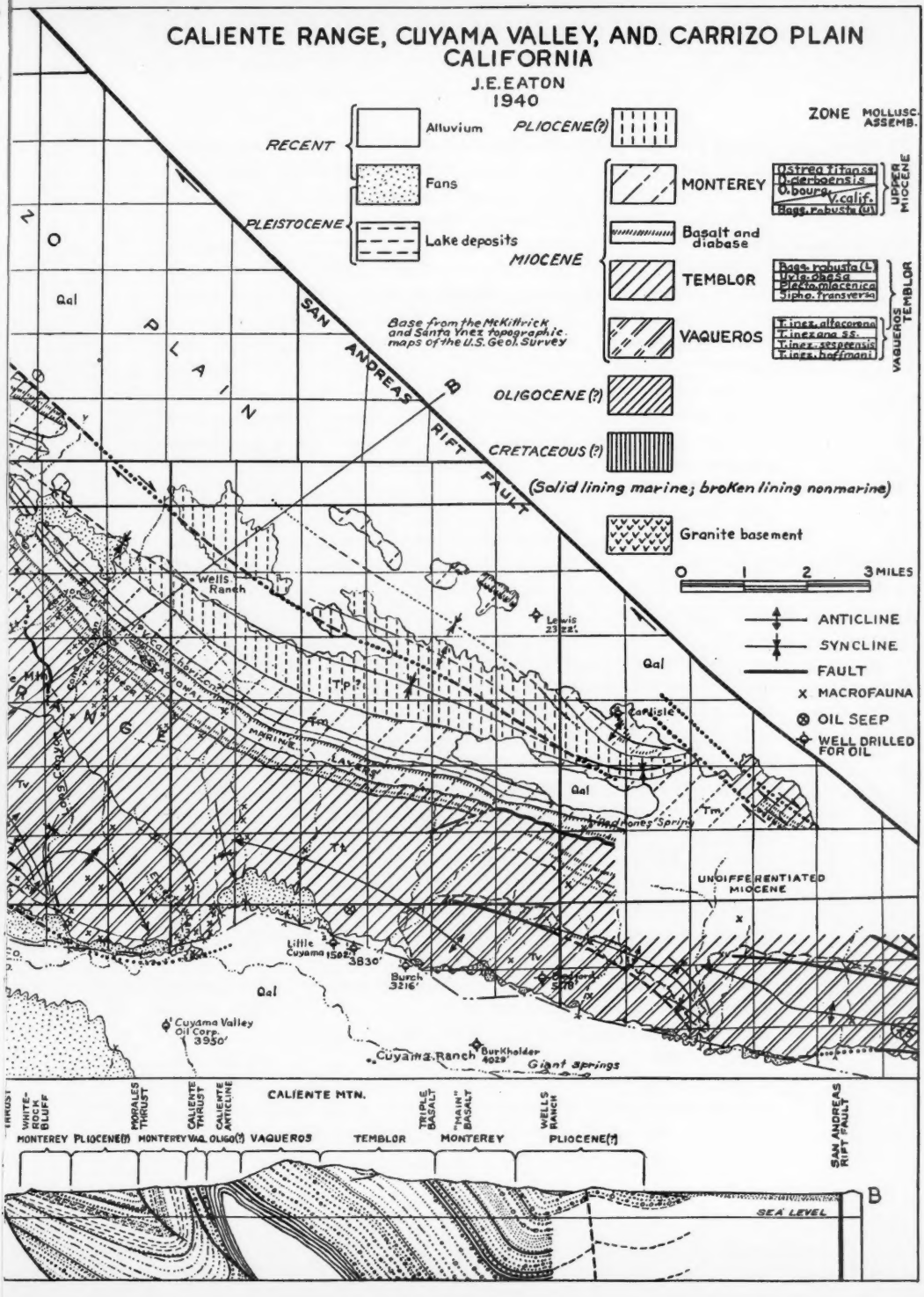

FIG. 3 (east half)

the line labelled "strike for equal texture," and at other times coarse, traction-laid sediments were deposited over nearly the entire district.

Though finer or coarser wedges extended at times nearer to or farther from the strands, and axes changed slightly with time, the persistence of relative average relations in the district throughout the Miocene is remarkable. This part of Caliente trough, which is near its head, was bounded by more or less persistent lands with a nearly static area of sedimentation between them. As a result, though extreme variation in physical facies is found vertically, with alteration from conglomerate to clay and back again, areal mapping shows that these changes followed recurring similar paths and had the same strikes to a degree that left relative relations almost unchanged throughout the Miocene. In part to this feature is due optimum areas for mulluscan and echinoderm life, one of which gives a persistent faunal record for lower and middle and the other for upper Miocene time, whose boundaries persisted with little change for millions of years. As an example of persistence, the strike for equal textures in the Temblor and Monterey of the northeast flank of Caliente Range remains approximately N. 27° W. for the twelve miles that this can be traced. This strike is somewhat unusual in that it crosses the structural basin diagonally, and persisted with little change throughout the Miocene.

Sufficient data are available to contour both equal total thickness and the somewhat discordant equal average texture with a degree of accuracy. In an endeavor to show a multitude of related physical and faunal features in Figure 2 without obscuring a whole, both sets of contours have been omitted. The point of maximum subsidence and thickness is indicated by arrows on the longitudinal axis for these features, which should enable the reader to visualize mentally more or less evenly spaced contours of thickness showing a relatively rapid thickening from the strands toward this point, and a relatively slow thickening from the ends of the axis toward it. In lieu of contouring equal average texture one intermediate contour is shown as a double line labelled "strike for equal textures." From this line, and that showing the axis for finest textures, other contours for equal average texture can be prorated. (It should be noted that such contours on the northeast cut diagonally across contours of thickness.) Spacing of both sets of contours, if constructed, would be representative of conditions for the Vaqueros and Temblor. In Monterey time the general relation persisted, but a pronounced structural flattening of the basin of deposition then resulted in more widespread coarse sediments whose thickness and texture, while variable, are more nearly uniform over the district.

Optimum faunal belts.—Marine invertebrate faunas, both mega- and microfaunal, locally occur in the district where textures, depths of water, salinity, *et cetera* were favorable. Mollusks here occur particularly where basal conglomerates of any horizon advanced after an unconformity, and widely in the shallow-water upper Miocene. Over much of the district megafossils occur in the usual manner in California of occasional fossiliferous beds separated by a thousand or so feet of essentially barren beds.

In certain elongate closed belts of Caliente Range and environs, on the other hand, mollusks and (or) echinoids are found more or less continuously throughout thousands of feet of the Miocene series (Fig. 2). In an optimum life belt crossing Caliente Mountain diagonally, molluscan faunas have been collected a few hundred feet apart through 9,200 feet of Vaqueros and Temblor (lower and middle Miocene) strata furnishing about 30 consecutive horizons, a uniquely persistent faunal sequence in California, where mollusks are rarely found consecutively through more than a few hundred feet of these stages. At and east of Bitter Creek in southern Cuyama Valley a narrow, strandward belt of locally vertical Monterey (upper Miocene) strata 2,700 feet thick furnishes an optimum belt for echinoids and oysters, which occur in reefs a few feet to a hundred or so feet apart throughout the section. A wedge-shaped foraminiferal optimum in the Temblor and lower Monterey along the axis for finest textures is merely usual, since foraminiferal optimums are rather common in the state.

The elongate molluscan optimum passing diagonally through Caliente Mountain is particularly interesting to the writers because its location and outline seem to throw light on some factors contributing to the preservation of fossils. The most abundant molluscan remains average about the center of this area shaded in Figure 2, the preserved remains decreasing outward. The basic cause of this elongate optimum area was presumably a persistent belt of favorable depths of water combined with favorable textures. But such favorable conditions would seem to have extended as a wider or narrower band paralleling the shore around much of the head of the trough. Then why does the optimum area taper rapidly at each end? Particularly, why did it maintain this taper rather rigidly during two-thirds of the Miocene?

The writers incline toward the view that the present outline of the optimum bounds, in part, an optimum belt, but is controlled to a large extent by the boundaries of an area of optimum preservation. According to this theory, life was perhaps abundant in a longer band, but its record was preserved chiefly in a segment of this. They note that the richest fossil record is found not only where the strike for favorable

textures (and presumably for depths) crosses the axis for maximum subsidence, but is exactly at the point of thickest deposition in the basin, and, therefore, supposedly in the area of the most frequent rapid burials of marine organisms. At present mollusks live in vastly greater abundance in the neritic zone of the California coast than one would compute from their occurrence fossil.

It is apparent that the great bulk of the shells in the neritic zone are eventually ground to fragments by waves and currents, and that, on the whole, only small quantities buried by occasional rapid shifts of material tend to be preserved. The present writers postulate that the radiating of the optimum belt at and near Caliente Mountain from the point where an axis for favorable depths and textures intersects the axis for maximum subsidence and thickness is probably not a coincidence, but may reflect optimum preservation through locally rapid burial at intervals of perhaps a few hundred or few thousand years. The Bitter Creek echinoid optimum appears to be corroborative. Though agitation was there so strong that of hundreds of *Ostrea titan* valves originally a foot long and several inches thick only small, rounded fragments remain, the fragile *Astrodapsis*, more than 90 per cent of which are ground to coquina, occasionally lie as they lived, almost perfect and rim to rim, along planes where they must have been quickly buried, at intervals, by a thin layer of white, shifting sand. In this general connection the most favorable condition for the preservation of fossils in the neritic zone is apparently not rapid total deposition, but an occurrence of occasional rapid shifts of sediment which will bury fossils before they can disintegrate.

Paleogeography.—Figure 4 presents paleogeographic maps of Caliente Range and environs at various averaged stages during the Oligocene(?) and Miocene, with a generalization for the Pliocene. The various boundaries, necessarily approximate, have been calculated from the apparently complete upper Oligocene(?) and lower and middle Miocene succession in Caliente Range, overlaps west and southwest in Cuyama Valley and in southern San Joaquin Valley, and gradations from marine to continental deposits. Scattered windows in Cuyama Valley revealing that certain horizons are there absent at unconformities, and overlaps, thinning wedges, and beach facies on edges of this valley give a fair control, but the valley exposures are too scattered to delimit ancient strands closer than within a mile or so of their actual positions. Marine-continental contacts represent averages, for the two facies commonly grade to one another in an oscillating series of wedges along an inclined plane. The more important relation, that between stages, is believed to be approximately as shown. In this particular fig-

ure relations across the San Andreas rift are drawn as these are computed to have existed at the times illustrated, prior to horizontal offsetting along this rift. Features shown northeast of this rift must be moved by the eye approximately 25 miles southeastward to obtain the relations which exist at present.

SOURCE OF MATERIALS

That more than 90 per cent of the total materials came from the northeast and less than 10 per cent from the southwest in the area mapped is obvious from the very unequal areas flanking the axis for finest textures in combination with the fact that the thickest deposits are northeast of this axis. The northeastern or major source was presumably mountainous, for gravel lenses have been observed on that flank through much of the Miocene series, the sands tend to be rather freshly arkosic, and persistent strikes for equal texture seem to preclude any large reëntrants. The southwestern or minor source was apparently much lower, for gravel, except for the lower Vaqueros, is almost absent at its strand even in transgressing basal beds, and at least two broad reëntrants occurred in Vaqueros and one in Monterey time. Judging from converging axes and the strikes for equal textures toward the northwest, the relative proportion of materials derived from the southwest seemingly increased, and that from the northeast decreased, in this direction. Northwest of the district mapped the relative average contributions may be reversed.

The northeast or major source leads to some radical conclusions. Such are believed necessary if any possible source is to be found. The Miocene deposits on the northeast flank of the basin, containing about 200 cubic miles of traction-laid material, progressively coarsen toward the present San Andreas rift as far as exposures are available, and become increasingly, if not entirely, continental in this direction. Scattered exposures of deformed strata, apparently continental, are present within about one mile of the San Andreas rift. Any highland which could conceivably have existed between the exposures and the rift could not have furnished more than a few per cent of the deposit. The general relations indicate that there were no highlands in the district southwest of the present rift.

The problem is this: the district deposits coarsen and become increasingly continental toward, and seemingly to, the present line of the San Andreas rift, but when we at present step northeast across this rift we find ourselves in the prevailingly fine-grained marine Miocene of Temblor Range, chiefly marine middle and upper Miocene shales equivalent in age to coarse continental deposits in Caliente trough on

the southwest side of the rift. The appearance given is that the coarse continental deposits were derived from the contemporaneous relatively fine-grained marine shales. The writers can not accept such an origin.

The continental deposits could not have come from the La Panza Range far to the west-northwest (where there are similar beds derived from this range), because the La Panza Range is on the opposite side of Caliente trough, with intervening marine shales; or from any hypothetical mountain range in northwestern Carrizo Plain, partly because the known trend of Caliente trough precludes the possibility of more than a sliver of any such range there, but chiefly because the continental band and the coarse marine band both narrow in that direction (Fig. 2); or from the *present* site of the San Emigdio Mountains on the east-southeast, for, considering the nearly parallel strike both of marine textures and marine-continental boundaries, the materials, continental and marine, must under any such interpretation have travelled northwest 20 or more miles in a strip from zero to one mile wide along the San Andreas rift, and then have turned southwest at nearly a right angle. This list seems to conclude the normal possibilities.

Some geologists have hesitated to believe that horizontal movement totalling many miles has occurred along the San Andreas rift in post-Miocene time, though evidence tending to show such has been presented by many workers. To the writers, the only possible source for the sediments on the northeast flank of the district discussed appears to be the San Emigdio Mountains standing at the site, in Miocene time, where the southern Temblor Range now stands. This postulate involves a horizontal movement along the rift of 20–25 miles in post-Miocene time. Since the indicated movement is in accord with the known direction of actual movement along this rift in historic time, only its amount need be discussed.

Horizontal shifts along the San Andreas rift ranging up to 21 feet were measured after the San Francisco earthquake of 1906. If it is assumed that shifts on the order of 10 feet occurred as an average only each 500 years, and that only half of the mapped course of the rift moved at any one time, the total horizontal offsetting since the Miocene would approximate the amount required. Noble[17] has inferred a possible total of 24 miles locally from a suggested offsetting of sediments. Miller[18] infers a horizontal shift of at least 15 miles from a wide

[17] L. F. Noble, "The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California," *Carnegie Inst. Washington Year Book 25* (1925–26), p. 420.

[18] W. J. Miller, "Geology of the Western San Gabriel Mountains of California," *Univ. California at Los Angeles Pub. Math. and Phys. Sci.* (1934), p. 79.

belt of mixed rocks on one side of the rift paralleled by a wide belt of mica schist on the other side over this distance. Northwest of San Benito the rift divides into several branches which divide the total throw. A total horizontal throw ranging from 1 to 12 miles has been computed along individual branches of the rift by workers in this locality of divided throw.

In the district particularly discussed numerous stream courses are horizontally offset along Elkhorn Scarp where they cross the rift. Wood and Buwalda[19] state:

> The evidence indicates clearly that the block west of the fault has moved northward relative to the eastern block at least several thousand feet in very recent time; the drainage courses are very young features. Total horizontal displacement of much greater magnitude, measurable in terms of many miles, or in tens of miles, is thereby strongly intimated.

A series of drag ridges pointing northwest have been observed here along and roughly parallel to the rift by the writers, one overlapping the other, for several miles. The ridges average about ½ mile in length, and in this distance taper from an average height of about 200 feet above the plain, to the plain. This reveals about ½ mile of horizontal displacement while approximately 200 feet of soft, shattered sediments were being eroded, the ridges being perpetually limited, despite continuing rejuvenating movements, to a length of about ½ mile by the ratio between erosion and displacement. The southern Temblor Range of which they form foothills has been degraded amounts ranging up to 8,000 feet, and parts of the adjacent Caliente Range up to twice this amount, in post-Miocene time. Dividing the unit for erosion into the total degradation suggests 20–40 miles of post-Miocene horizontal displacement, which is on the order of the 20–25 miles required to reconcile the observed depositional relations on the two sides of the rift.

STRATIGRAPHY

NOMENCLATURE

Coastal California differs from most other marine provinces of the United States in the feature that instead of having broad sheets of stratified deposits laid down in epeiric seas its Cenozoic strata were deposited in a network of bays and straits on a relatively narrow shelf between highlands and the abyss. Mountainous, irregular peninsulas divided this narrow shelf into isolated marine basins or groups of basins, and caused the strata to lens, in many places in a mile or two basinward, from conglomerate to clay. Extreme Pleistocene degrada-

[19] H. O. Wood and J. P. Buwalda, "Horizontal Displacement along the San Andreas Fault in Carrizo Plain, California," *Pan-Amèr. Geol.*, Vol. 54, No. 1 (1930), p. 75.

tion further isolated different textural groupings, with the result that while some characteristic average aspects of the sediments deposited during a major stage tend to be traceable almost state-wide, the actual formations *sensu stricto* comprise a practically innumerable group of narrow textural lenses and remnants of lenses which average 2 or 3 miles in width and 20 or 30 in length. It has been estimated that due to this extreme lensing approximately 500 formation names would be required if the Tertiary cartographic units of California were to be designated separately in the manner of the eastern and central United States. To divide California Cenozoic deposits into hundreds of separately named formations that grade one into the other in a few miles is not practical.

Prior to the twentieth century separate names were prevailingly used for the ever-changing wedges. Early in this century it was perceived that to continue this practice would soon result in intolerable confusion. As a result, faunal groupings were ascertained, the names of about a dozen local Cenozoic formations having priority were applied to these, and the resulting stages were carried from basin to basin regardless of the innumerable physical facies. Errors were made and still exist, but the choice was between a standard column and a profusion of names approaching chaos; between a practical system that describes the ever-changing local facies of a dozen stages, and several hundred intergrading named wedges with necessarily assumed boundaries whose number alone would defeat correlation. When a geologist in California uses the standard marine terms Martinez, Meganos, Domengine, Tejon, Vaqueros, Temblor, Monterey, Briones, Cierbo, Neroly, Jacalitos, Etchegoin, San Diego, Santa Barbara, or San Pedro away from their types he does not refer to a conventional formation but to a stage or substage. He is referring to sediments, laid down during a time horizon, which tend to have certain broad, state-wide similarities of average aspect, but which comprise from place to place perhaps half a hundred actual formations.

A formation is properly a physical facies or rhythmic group of facies over the area where this is more or less definitely traceable. When an originally local term comes to designate in general usage a major faunal horizon regardless of physical facies or continuity of beds it becomes a stage. Facies descriptions are then no longer applicable to the whole. For instance, strandward horizons of the Monterey "shale" are now indicated to contain more coarse material than does the entire Vaqueros "sandstone," the suffixes having been originally applied to local facies.

The Miocene terms Vaqueros, Temblor, and Monterey, originally

applied to more or less local facies, have been used for a generation in the sense of time horizons. Long usage has established them as designating all marine sediments of the California province, regardless of facies, that carry faunal assemblages characteristic of the original type. They represent the three largest natural divisions of the California Miocene. Each of these faunal stages, however, though comprised of an almost infinite number of intergrading physical facies, coincides over most of coastal California with a more or less regionally characteristic average type of deposition. The practice of referring to them as formations when a time horizon is actually meant has therefore been prevalent. No serious error is involved in such a usage, because it has been understood that the tendency for each faunal stage to coincide with a somewhat characteristic average type of deposition, and not the aspect of local wedges, is the meaning intended. On the other hand, it is to be noted that the proof is faunal, and that the proper usage is stage.

In the present paper marine sequences of Caliente Range and environs yielding adequate faunas are described as areally changing facies of standard stages and substages, no attempt being made to erect formations in a series that is areally a continual and ever-changing gradation from conglomerate to shale.

CRETACEOUS(?)

Dark silt and thin to heavy-bedded sandstone which according to English[20] locally exceeds 9,000 feet in thickness bounds Cuyama Valley on the southwest, west, and northwest as rugged and somber mountain ranges. Silt appears to dominate southwest, and sandstone northeast, of Cuyama River. The sandstones are commonly well cemented, hard, and individually resistant, but alternate with silt members at such frequent and rhythmic intervals that they do not stand out, the whole weathering to a dull, dark, brush-covered sequence which from a distance gives an appearance of homogeneity. The general series, which is much older than Caliente trough, underwent strong deformation before Miocene deposits which rest with extreme unconformity on it were laid down, having been folded, jointed, recemented, and deeply eroded in some long pre-Miocene interval.

No fossils have thus far been obtained by the writers from the sequence. A poorly preserved *Pecten* reported by English[21] as having been found in it may have come from fossiliferous Vaqueros windows such as those west of Schoolhouse Canyon and at the mouth of Cotton-

[20] *Op. cit.*, p. 197.

[21] *Ibid.*

wood Canyon which he mapped with the Cretaceous(?). Lower parts of the sequence resemble fossiliferous Cretaceous of the Diablo and northern Temblor ranges, and are possibly of similar age, but upper parts may be proved to be younger.

The series forms the foundation underlying western Cuyama Valley, and, except for a small exposure of granite on the extreme northwest, perhaps much of the district discussed, as is shown by windows of Cretaceous(?) in the former area overlain by Vaqueros with extreme discordance. In this connection, however, at least one of the windows near Schoolhouse Canyon previously mapped as Cretaceous (?) contains, as mentioned, Vaqueros and (or) Temblor pectens. As a rule the Cretaceous(?) is so different in aspect from the Vaqueros that little difficulty is experienced in segregating the two except in isolated, weathered windows. Relations to known Eocene rocks southeast of Cuyama Valley have not been determined; it is possible that shaly upper parts of the succession summarized may be of Eocene age.

EOCENE

The Eocene series, which is well developed in the San Emigdio foothill portion of the general trough and also southeast of Cuyama Valley, is not known to be exposed in the district discussed, but its presence in thickness immediately southeast of this district suggests that it may underlie parts of southeastern Cuyama Valley at depth. Gregersen[22] assigns in excess of 10,000 feet of grayish shales and buff sandstones southeast of Cuyama Valley, fossiliferous in upper parts, to the Eocene. He states that the relation of the sequence assigned to the Eocene in that region to the Cretaceous(?) which occurs on the northwest has not been adequately determined, but that the former appears to be in part younger than the latter.

OLIGOCENE(?)

About 1,100 feet of dark, chocolate to black silt almost devoid of prominent sandstones crops out at the core of the Caliente Mountain anticline. In Figure 5, a distant view of Caliente Mountain, this succession is visible on the extreme right as a black band lying immediately below the heavy-bedded Vaqueros sandstone and silt sequence of the mountain proper. In Figure 6, a view of Caliente scarp, part of this succession is again visible, being the dark, homogeneous silt underlying the lowest heavy-bedded sandstone of the Vaqueros. It has so far yielded no fossils. Similar silt, with some medium- to heavy-bedded

[22] A. I. Gregersen, oral communication (October 23, 1939).

gray to white sandstone which increases toward the base, crops out beneath the Vaqueros at the southeast end of Caliente Range to a thickness of 1,500 or more feet. Basal strata there contain poorly preserved Foraminifera as yet undetermined. Since this series is seemingly conformable with the overlying Vaqueros in both sections it is inferentially Oligocene, and a marine equivalent of the continental middle Sespe beds of Southern California. Its base is nowhere exposed in the district.

Marine Oligocene has been described as being present at the type San Lorenzo[23] near the mouth, and the type San Emigdio near a head[24] of Caliente trough. Connecting strata in the intermediate district being discussed are therefore to be expected. Caliente trough, as a whole, exposes the best evidenced and perhaps the only marine Oligocene in California. Precise relations between the marine Oligocene and the overlying Vaqueros (lower Miocene) are not clear near the mouth and head of the trough due to diagnostic forms not having been collected at these localities both immediately above and below a contact.

The Oligocene(?) at Caliente Mountain occurs conformably below a well exposed 4,500-foot full succession of Vaqueros (Fig. 6) yielding *Lyropecten* throughout and the oldest known variety of the *Turritella inezana* clan at its base, thus affording an unsurpassed section and superjacent faunal control. Even a fair foraminiferal fauna from this Oligocene(?) would thus be one of the most important in the state. Preliminary sampling has failed to yield adequate Foraminifera. It is hoped that some micropaleontologist can be induced to make a foot-by-foot collection of this Oligocene(?) and wash a hundred or more selected samples in the hope of obtaining an adequate fauna. Any such collecting should be done on the northwest side of Scarp Canyon, since on the southeast side faulted and landslid Vaqueros complicates the section in a series of steps (Fig. 3).

The Oligocene(?) of Caliente scarp is unusually fine-grained for deposits in a narrow bay. This feature is interpreted as indicating low lands approaching base level near the close of the Oligocene, a condition for California which has been previously inferred by other workers.

MIOCENE

Foreword.—The term Miocene, as this is ordinarily applied in California, designates a series having a coincident physical and faunal

[23] H. G. Schenck, "Nuculid Bivalves of the Genus Acila," *Geol. Soc. America Spec. Paper 4* (1936), p. 72, concludes that the type San Lorenzo is only in part older than the *Turritella inezana* zone of the Vaqueros.

[24] C. M. Wagner and K. H. Schilling, "The San Lorenzo Series of the San Emigdio Region, California," *Univ. California Pub. Dept. Geol. Bull.*, Vol. 14, No. 6 (1923).

unity so pronounced that apparently no part of it can be detached without violating a natural unit. Available marine invertebrate and terrestrial vertebrate evidence indicates the series to comprise an essentially complete sedimentary succession ranging in age from Aquitanian upward to or near the top of the so-called Sarmatian-Pontian sequence.[25] The Miocene series as commonly designated in California would thus seem to correspond in age at least roughly to this series as commonly recognized in Europe, although further data will be necessary before more than an approximate equivalency can be established. Its inception in California is characterized faunally by the first appearance of large heavy-shelled Pectinidae and giant turritellas, and its end by a change to the warm-temperate faunas of more restricted seas.

In full sections the Miocene series of California is divisible on the basis of coincident faunal and physical groupings into three nearly equal major stages: reading upward, the Vaqueros, Temblor, and Monterey, usually described as being respectively of lower, middle, and upper Miocene age, a local usage which does not necessarily precisely correspond with the usage of such terms in Europe. The Monterey (upper Miocene) of the state includes three named substages, the Briones, Cierbo, and Neroly. Indicated natural substages of the Vaqueros and Temblor have not as yet been named.

VAQUEROS (LOWER MIOCENE)

Type and history of the term.—The Vaqueros was named and described by Hamlin[26] in 1904, the type being designated as Vaqueros Canyon in Salinas Valley. A molluscan fauna was listed which included the guide forms *Turritella inezana* (*T. "hoffmani"*) and *Lyropecten magnolia*, the former of which has since become the titular head of an assemblage commonly known as the *Turritella inezana* fauna. Loel and Corey[27] have re-collected the type locality, have added to the list of characteristic species, and have corrected some and verified others of Hamlin's original determinations. They have apparently shown, by the occurrence of such uppermost Vaqueros markers as *T. inezana* var. *altacorona* and *Ostrea vaquerosensis*, that the top of the type Vaqueros as defined by Hamlin corresponds closely with the top of the widespread and characteristic so-called *Turritella inezana* fauna of Califor-

[25] According to data from H. F. Osborn, W. D. Matthew, Chester Stock, A. M. Davies, U. S. Grant, G. D. Hanna, T. W. Vaughan, W. P. Woodring, *et al.* Summarized in J. E. Eaton, "Tie-Ins between the Marine and Continental Records in California," *Amer. Jour. Sci.*, Vol. 237, No. 12 (December, 1939), pp. 899–919.

[26] Homer Hamlin, "Water Resources of Salinas Valley, California," *U. S. Geol. Survey Water Supply Paper 89* (1904).

[27] *Op. cit.*, pp. 115–22.

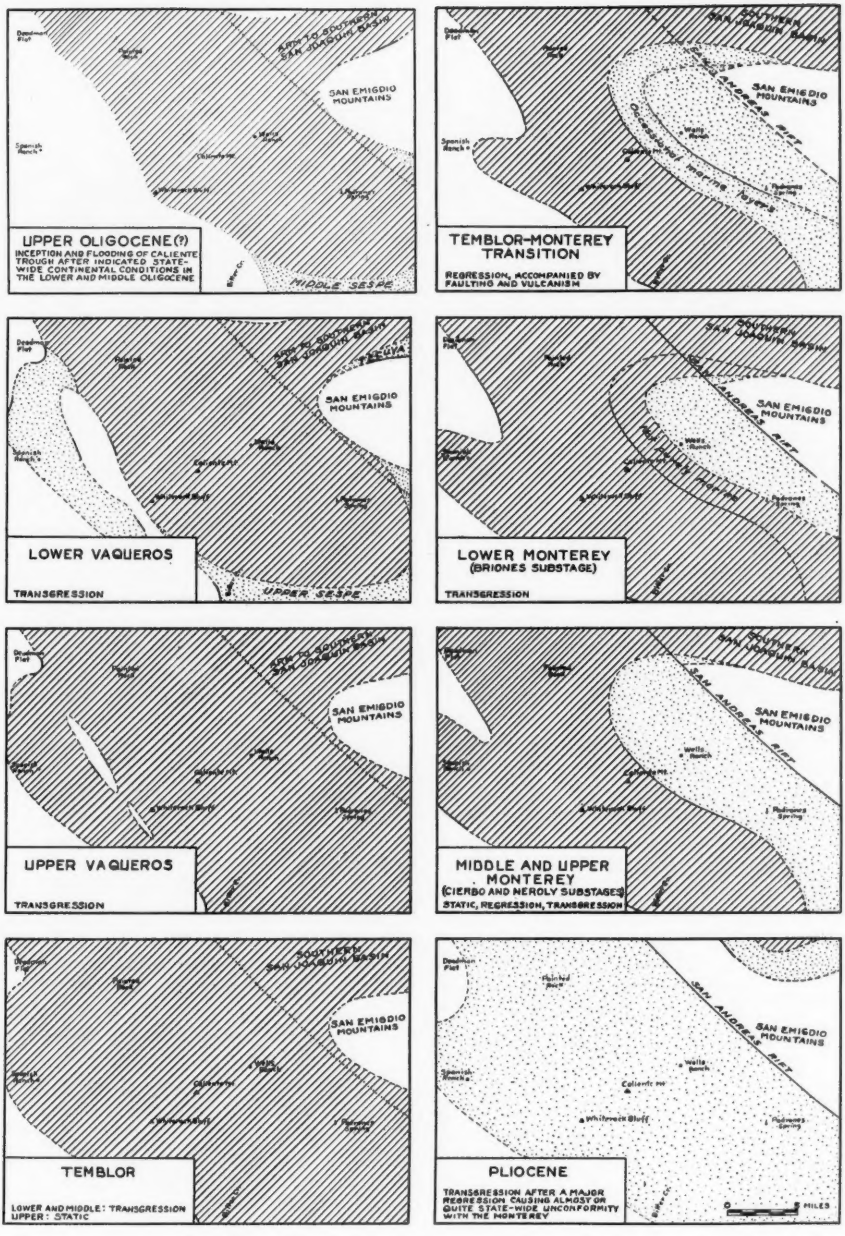

FIG. 4.—Paleogeographic maps of the particular district. Marine deposition, lined; non-marine deposition stippled. Proportions as of to-day, after extreme transverse shortening. Relations across the San Andreas rift fault as of the dates shown, before subsequent horizontal offsetting.

FIG. 5.—Caliente Mountain, looking northeast across Cuyama River. Banded Vaqueros of the mountain proper is thrust toward the camera over light-colored foothills of vertical to overturned Monterey. The crest line of these foothills, sloping gently downward to the right, approximates trace of main thrust. At Scarp Canyon (right) the Temblor is almost entirely cut out. It is about half emergent at Pinnacle Canyon (left).

FIG. 6.—Caliente scarp, looking northwest across Scarp Canyon. Near lower left corner is dark Oligocene (?) silt. The sandstone and silt section above this exposes the main body of the Vaqueros. Uppermost and transitional parts of this stage are not shown in the photograph. The light-colored double exposure at fog-shrouded crest of Caliente Mountain is the "Key White" sandstone, for which see Figure 7.

FIG. 7.—Detail in upper Vaqueros at top of Caliente scarp. The coarse, cavernous exposure is the "Key White" sandstone. Below this is the *Ostrea-Pecten miguelensis* zone, with the *Ostrea vaquerosensis* zone some distance above. This sandstone, in combination with fossiliferous reefs immediately below it, forms a prominent marker over much of the Caliente Mountain region. The Vaqueros-Temblor transition zone is higher than the summit strata shown.

nia. Goudkoff[28] and Rankin[29] have examined, and Kleinpell[30] has published, foraminiferal faunas from about 1,800 feet of shale conformably overlying the sandy type Vaqueros. They find that the base of the overlying shale represents the *Siphogenerina transversa* zone of coastal California. This zone elsewhere conformably overlies the *Cibicides americanus* zone. Though Foraminifera have not been obtained from the coarse type Vaqueros, from the conformable relations there and elsewhere the uppermost Vaqueros presumably represents the latter zone.

The term Vaqueros was quickly adopted by geologists for all marine strata of California yielding the distinctive *Turritella inezana* fauna, and has since been used for such strata almost to the exclusion of other terms.

Vaqueros of Caliente Range.—Resting with apparent conformity on the dark silt at the core of the Caliente Mountain anticline, and continuously exposed upward to and well beyond Caliente Peak, is approximately 4,500 feet of (basinward) marine Vaqueros yielding a molluscan fauna of this age that ranges from *Turritella inezana* var. *hoffmani* in the base to *T. inezana* var. *altacorona* in the top. The lower 1,000 feet is composed of alternating thick bands of dark green silty sand carrying thin finer-grained fossiliferous layers, and coarse, pebbly gray sandstone. Above this is about 700 feet of dark green silty sand and chocolate silt with occasional thinner sandstones. In the upper 2,800 feet heavy-bedded sandstone is dominant, the included silty sands becoming minor upward. The succession becomes on the average lighter-colored and less massive upward for about 3,300 feet (Fig. 6). At this point occurs a regionally prominent 150-foot *Ostrea-Pecten miguelensis* zone, above which are several hundred feet of coarse white sandstone (Fig. 7) with finer green sand partings (uppermost true Vaqueros), followed by several hundred feet of submassive gray sandstone and buff sand (Vaqueros-Temblor transition zone). The entire Vaqueros, which weathers a rusty gray, is here fossiliferous at more or less frequent intervals. The lower half yields almost exclusively Vaqueros species of mollusks. In the upper half some Temblor forms, notably *Turritella ocoyana* and *Echinarachnius norrisi*, are also present and even common. These latter remain prominent in the uppermost several hundred feet (transition zone), at the top of which Vaqueros guide fossils disappear. The range of *Turritella ocoyana* s.s. overlaps

[28] P. P. Goudkoff, oral communication.

[29] W. D. Rankin, oral communication.

[30] *Op. cit.*, pp. 7–19, Table 1, and Fig. 4.

(basinward only) the range of *T. inezana* s.s. 1,900 feet. The two species have not been observed to overlap strandward.

Southwest of the previously described section, on the southwest side of the Caliente Mountain anticline, the Vaqueros becomes progressively finer-grained, thinner, and less fossiliferous. The Caliente Mountain thrust fault here complicates the succession.

In the eastern part of Caliente Range two large anticlines expose respectively partial and complete Vaqueros successions similar to that at Caliente Mountain except that these are coarser, only sparingly fossiliferous, and have a maroon member near their middle.

Vaqueros of western Cuyama Valley.—In western Cuyama Valley, at and near Redrock and Taylor canyons, a thin, strandward succession of Vaqueros age overlaps on Cretaceous(?) north of Cuyama River. Lower, and perhaps early upper parts of the Vaqueros of Caliente Range are here represented by up to 550 feet of red, pebbly continental sandstone. The red, continental sequence grades conformably at its top into heavy-bedded white marine sandstone locally yielding the upper Vaqueros assemblage *Turritella inezana* s.s., *Lyropecten magnolia, et cetera*.[31] The white sandstone, which varies along the strike from 50 to 150 feet in thickness, grades upward, in turn, to several hundred feet of chocolate to gray silt and silty sand that darkens toward its top, this series containing hard, fine-grained brown reefs. Next above is several hundred feet of soft, pebbly gray sandstone yielding the Temblor assemblage *Turritella ocoyana* and *Vertipecten nevadanus* near its base. Overlying these beds unconformably are Pliocene(?) continental gravels composed in part of redeposited siliceous Miocene pebbles. Much or all of the Monterey appears to be absent at this particular locality.

The silty sequence mentioned as lying between the two faunas is for convenience mapped in Figures 3 and 8 with the underlying Vaqueros, but much of it is probably lower Temblor in age. The basal red continental deposits, the overlying white sandstone, and a lower part of the silty series, locally totalling about 800 feet of strata, are seemingly a thin strandward equivalent of the thick basinward Vaqueros of Caliente scarp. West of Figure 3 the Vaqueros is overlapped by upper Monterey (Neroly substage) which rests on the Cretaceous(?).

Vaqueros of southwestern Cuyama Valley.—A window surrounded by late Pleistocene terrace fill in the first canyon west of Schoolhouse

[31] English (*op. cit.*) correctly assigned a thicker but otherwise somewhat similar continental red and overlying fossiliferous white marine sequence in southern Cuyama Valley to the Vaqueros. In the western Cuyama Valley region above discussed, however, where he did not find fossils, he mapped all Vaqueros and Temblor strata as Santa Margarita.

Canyon exposes about 1,500 feet of steeply dipping, homoclinal, hard rusty gray and pinkish heavy-bedded sandstones. Large pectens occur in the upper two-thirds, but the rocks were found to be too hard to admit of collecting these. Much of this sequence is presumably Vaqueros.

Farther southeast, between Branch and Pato canyons (south of Fig. 3), strandward Vaqueros is exposed almost continuously for 20 miles as irregular bands lying unconformably upon or faulted against Cretaceous(?) and Eocene beds and croppingout along the crest of anticlines. The Vaqueros is here somewhat similar in aspect to that of western Cuyama Valley but is much thicker than at that locality. The lower, continental, reddish portion grades up to coarse, submassive white marine sandstone yielding at its base the same upper Vaqueros assemblage of *Turritella inezana* s.s. and *Lyropecten magnolia* as in western Cuyama Valley. This, in turn, grades up to gray and buff sand with large brown concretions locally containing Temblor mollusks.

FAUNA OF THE VAQUEROS

Table I lists thirty-two consecutive basinward megafaunas collected a few hundred feet apart through 4,500 feet of Vaqueros, 4,700 feet of Temblor, and the lower 500 feet of superjacent Monterey strata in Caliente Range on the northeast flank of the Caliente Mountain anticline, together with one strandward upper Vaqueros fauna from near the mouth of Cottonwood Canyon in Cuyama Valley. The jump from field horizon 32 to field horizon 90 does not represent a gap, but the circumstance that collecting proceeded both up from the bottom and down from the top of the section, with the result that the absent intermediate numbers represent an unused reserve. Similarly, fractional field numbers do not represent fractional horizons, but the circumstance that when gaps were later collected whole numbers were not available. The stratigraphic position of each numbered megafauna is shown in Figure 8, at the side of the column titled "Northeast Flank of Caliente Mt. Anticline," by the lower thirty-two occurrences of the letter M. Collections listed in this table have been deposited at the University of California at Los Angeles, where they are filed under both field and University numbers.

Some of the more useful turritellas of the California Miocene are figured in Plate I. All fossils figured in the present paper are from Caliente Range and environs with the exception of *Turritella inezana* var. *bicarina*, *T. inezana* var. *sespeensis*, and *T. inezana* var. *santana*, whose horizons are continental strandward and apparently too cool basin-

TABLE I

	Stage	Monterey	Temblor									Vaqueros																								
	Horizon	17	17½	18	18¼	18½	19	20	21	22	22½	23	24	24½	25	26	26½	27	Cotton-wood	28	30	31	32	90	91	92	93	94	95	96	97	97½	98	99		
Echinoidea																																				
Echinarachnius norrisi (Pack)		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	x	—	—	—	—	—	—	—	—		
Echinarachnius sp.		—	—	—	—	x	—	—	x	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	x	—	—	—	—	—	—	—	—		
Pelecypoda																																				
Anadara aff. *osmonti* (Dall)		—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Cunearca aff. *gailei* (Wiedey)		—	—	—	x	x	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Amusium lompocensis (Arnold)		—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Chlamys sespeensis (Arnold)		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Leptopecten andersoni (Arnold)		—	—	—	—	x	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Leptopecten andersoni (Arnold) var. a		—	—	—	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Lyropecten crassicardo (Conrad)		—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Lyropecten magnolia (Conrad)		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Lyropecten miguelensis (Arnold)		—	—	—	—	—	—	—	—	—	—	—	x	x	x	x	x	x	—	x	x	x	x	x	—	x	—	x	x	x	—	—	—	—		
Pecten sp.		—	—	—	—	x	x	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Vertipecten nevadanus (Conrad)		—	—	—	—	—	—	x	x	x	—	x	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—		
Anomia vaquerosensis Loel & Corey		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—		
Antigona carrizoensis Loel & Corey		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	x	x	—	—	—	—	—	—	—	—	—	—	—		
Antigona vaquerosensis Loel & Corey		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	?	—	—	—		
Antigona n. sp.		—	—	—	—	—	—	—	—	—	—	—	x	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Antigona sp.		—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Chione schencki Loel & Corey		—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Chione temblorensis (Anderson)		—	—	x	x	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Chione sp. a		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—	—	—	—	—	—	—	—	—	—		
Chione sp. b		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—		
Clementia pertenuis (Gabb)		—	—	x	x	—	—	—	—	x	x	—	x	—	—	x	—	—	—	—	x	x	x	—	x	—	—	—	—	—	—	—	—	—		
Diplodonta buwaldana And. & Mart.		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Diplodonta harfordi Anderson		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	x	x	—	x	—	—	—	—	—	—	—	—	—		
Dosinia sp.		—	—	x	x	x	—	x	—	x	x	—	x	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—		
Lucina acutilineata (Conrad)		—	—	—	—	—	—	—	—	—	—	—	x	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Lucina sanctaecrucis (Arnold)		—	—	—	—	x	x	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Macoma nasuta (Conrad)		—	—	x	x	x	—	—	—	—	—	—	x	—	x	x	—	—	—	—	x	—	—	—	—	—	—	—	—	—	x	x	—	—		
Mytilus aff. *expansus* Arnold		—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—	—	—	—	x	—	—	—	—	—	—		
Mytilus loeli Grant		—	—	—	—	?	—	—	x	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—		
Nuculana? sp.		—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Ostrea altatemblorensis Grant & Eaton		—	x	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Ostrea aff. *eldredgei* Arnold		—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—		
Ostrea vaquerosensis Loel & Corey		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Pinna alamedensis Yates		—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Pinna sp. a		—	—	—	—	x	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Pinna sp. b		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—		
Psamosolen gabbiana (And. & Mart.)		—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Pteria hertleini Wiedey		—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—		

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ward for these tropical varieties in the district, and the holotype of *Astrodapsis hootsi*. New species and varieties are sponsored by those particular authors who identified them.

The basic traverse for the collections listed in Table I was northeast along the southeast edge of Scarp Canyon to the "Key White" sandstone just below Caliente Peak, then an offset southeasterly along this sandstone to the first ridge east of Long Canyon, then northeast along this ridge and the connecting ridge east of Cone Canyon. Collections from Pinnacle Canyon on the northwest and Ernest's Canyon on the southeast ends of the elliptical Vaqueros outcrop were tied in by means of the "Key White" sandstone, which can be traced to and around these ends. One fauna from Padrones Spring is tied in by its position between two flows of basalt which precisely connect this area and the basic traverse.

In Cuyama Valley upper Vaqueros faunas have been collected at and near the mouth of Cottonwood Canyon (listed), 2 miles northeast of the mouth of Carrizo Canyon, and 5 miles above the mouth of Santa Barbara Canyon, all from strandward, shallow-water facies, and all in the lower few feet of coarse, white, upper Vaqueros sandstone, the first from strata overlapping upon Cretaceous(?), and the other two from strata grading conformably up from red continental beds of lower or early upper Vaqueros age. The strandward fauna consists chiefly of *Lyropecten magnolia*, with occasional *Turritella inezana* s.s., rare *Chlamys sespeensis*, and, locally, *Ostrea eldredgei*.

No Foraminifera have been obtained from the Vaqueros of the district. However, the finer facies of this age have not been sampled.

No search has been made for terrestrial vertebrates in the reddish continental strata of lower and early upper Vaqueros age in western and southern Cuyama Valley.

Ecology.—The circumstance that the axis for finest textures and (generally) deepest waters was near the southwestern strand, whereas the geographical axis of the bay was near the shallower waters of Caliente Range, complicates usage of the terms "strandward" and "basinward." Throughout this paper the terms strandward and basinward are used in a geographical sense, for the reason that, though Cuyama Valley had *in general* deeper waters than those prevailing in Caliente Range, the particular megafaunas observed in this valley were all collected so near sheltered strands that they apparently lived in shallower, warmer waters than did those of the open-water Caliente Range.

The far strandward (sheltered and warmer water) upper Vaqueros yields a strictly Vaqueros assemblage, whereas this horizon in the ba-

sinward Caliente Range (open and cooler water) yields a mixture of Vaqueros and Temblor forms. This relation suggests marked ecologic differences. For example, in the upper Vaqueros the characteristic Vaqueros forms *Lyropecten magnolia* and *Turritella inezana* s.s. are locally common strandward but are rare basinward, whereas the Temblor forms *Turritella ocoyana* s.s., *T. ocoyana* var. *bösei*, and *Echinarachnius norrisi* have not been found strandward in the upper Vaqueros but occur abundantly as an admixture in these strata basinward associated with Vaqueros guides. It is to be emphasized that the basinward faunal assemblage mentioned is not Temblor, but is characteristic upper Vaqueros with a Temblor admixture. Outside of Caliente trough such admixtures basinward have so far been reported only from seaward portals of the Santa Ana and Santa Barbara embayments, the exposed upper Vaqueros elsewhere being almost universally a strandward deposit yielding a consistently Vaqueros fauna.

Ecologic change in the fauna of the upper Vaqueros of the district can be followed step by step along a line which strikes eastward from the mouth of Cottonwood Canyon diagonally toward more open, cooler, and locally deeper waters. Near the mouth of this canyon abundant *Lyropecten magnolia*, occasional *Turritella inezana* s.s., and rare *Chlamys sespeensis* are found in upper Vaqueros white sandstone unconformably overlapping upon Cretaceous(?). All of these forms are Vaqueros guides, and no Temblor forms are present. In Pinnacle Canyon 5 miles diagonally basinward *Lyropecten magnolia* and *Chlamys sespeensis* have not been found in the upper Vaqueros, but *Turritella inezana* s.s. and other Vaqueros guides are present accompanied by a few specimens of the Temblor form *Turritella ocoyana* that have crept in. Two miles farther basinward the occurrence of these two species of *Turritella* is approximately equal. One more mile basinward, hundreds of specimens of *T. ocoyana* and only two specimens of *T. inezana* s.s. have been collected from the upper Vaqueros; several Vaqueros guide species occurring vertically in their regional order show that the succession is upper Vaqueros in age, but several common Temblor species are so prevalent that a casual visitor who encountered only these might infer that it is Temblor. Though slight areal differences in depth of water were presumably present and involved, the feature that similar textures and shallow-water genera prevail at each station, and that the faunal change basinward involves a progressive displacement of what appear to be tropical species by subtropical ones, suggests that the dominant ecologic factor was a progressive lowering of temperature toward the more open waters. The circumstance that both here

and elsewhere in California the tropical Vaqueros fauna disappeared and the subtropical Temblor forms moved strandward at the inception of regionally cooler waters in Temblor time would seem to favor this interpretation.

TEMBLOR (MIDDLE MIOCENE)

Type and history of the term.—The Temblor was named and described by Anderson[32] in 1905, the type being designated as Carneros Creek in San Joaquin Valley. A megafauna was listed which included characteristic components of the so-called *Turritella ocoyana* fauna. Adoption of the term as a standard time unit was delayed for several years by an early belief of Anderson and contemporaneous workers that the Vaqueros and the Temblor were time equivalents; since the term Vaqueros had priority, the term Temblor could not come into regional use. However, Smith[33] and other paleontologists soon recognized that at least most of the type Temblor was younger than the type Vaqueros, whereupon the term Temblor was adopted as standard. Subsequent workers have established the fact that the change between the so-called *Turritella inezana* and the so-called *Turritella ocoyana* faunas represents the most distinct faunal change in the lower two-thirds of the marine Miocene of California.

Restudies of the type Temblor have shown that Anderson included approximately 300 feet of strata of Vaqueros age in the base of his type, this basal portion yielding upper Vaqueros mollusks[34] and representing the *Cibicides americanus* zone of micropaleontologists. Current practice therefore restricts the type Temblor to that part of the typical succession which lies above strata of Vaqueros age (Fig. 8). The type is overlain by at least parts of the *Baggina robusta* zone which represent a faunal transition that intervenes between the typical Temblor and the typical Monterey horizons; hence, there can be no conflict between the latter two types. The Temblor of California is characterized by the so-called *Turritella ocoyana* fauna, subject to the range of the *Turritella inezana* fauna below and the *Valvulineria californica* s.s. fauna above.

Temblor of Caliente Range.—Conformably overlying the Vaqueros of Caliente scarp, and forming the northeast flank of Caliente Mountain, are 4,700 feet of Temblor beds, also fossiliferous at short intervals. A full Temblor section can here be measured only along and im-

[32] F. M. Anderson, "A Stratigraphic Study in the Mount Diablo Range of California," *Proc. California Acad. Sci.*, Ser. 3, Vol. 2 (1905), pp. 155–248.

[33] J. P. Smith, "The Geologic Record of California," *Jour. Geol.*, Vol. 18, No. 3 (1910), pp. 216–27.

[34] Alex Clark, manuscript.

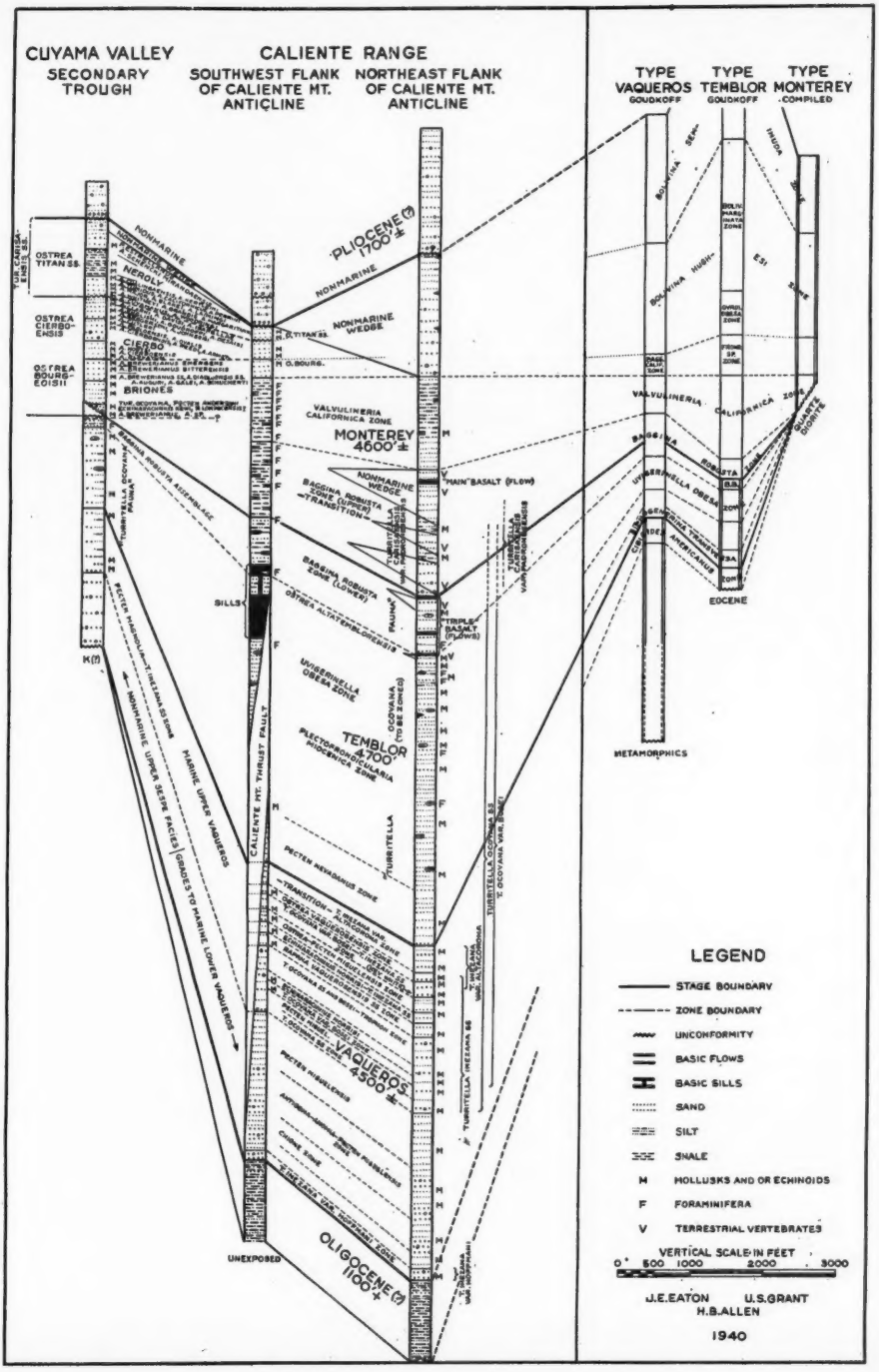

CUYAMA VALLEY
SECONDARY TROUGH
CALIENTE RANGE
SOUTHWEST FLANK OF CALIENTE MT. ANTICLINE
NORTHEAST FLANK OF CALIENTE MT. ANTICLINE
TYPE VAQUEROS GOUDKOFF
TYPE TEMBLOR GOUDKOFF
TYPE MONTEREY COMPILED
PLIOCENE (?) 1700'±
NONMARINE
OSTREA TITAN SS.
OSTREA CIERBOENSIS
OSTREA BOURGEOISII
CIERBO
BRIONES
MONTEREY 4600'±
VALVULINERIA CALIFORNICA ZONE
MAIN BASALT (FLOW)
BAGGINA ROBUSTA ZONE (UPPER) TRANSITION
BAGGINA ROBUSTA ZONE (LOWER)
OSTREA ALTATEMBLORENSIS FAUNA
SILLS
TRIPLE BASALT (FLOWS)
UNIBERNELLA OBESA ZONE
OCOYANA (TO BE ZONED)
TEMBLOR 4700'±
PLECTOFRONDICULARIA HIGGINSI ZONE
TURRITELLA
PECTEN NEVADANUS ZONE
CALIENTE MT. THRUST FAULT
TRANSITION
VAQUEROS 4500'±
PECTEN HINDSENSIS
CUDDIA ZONE
OLIGOCENE (?) 1100'±
UNEXPOSED
K(?)
NONMARINE UPPER SESPE FACIES GRADES TO MARINE LOWER VAQUEROS
MARINE UPPER VAQUEROS
EOCENE
METAMORPHICS
LEGEND
STAGE BOUNDARY
ZONE BOUNDARY
UNCONFORMITY
BASIC FLOWS
BASIC SILLS
SAND
SILT
SHALE
M MOLLUSKS AND OR ECHINOIDS
F FORAMINIFERA
V TERRESTRIAL VERTEBRATES
VERTICAL SCALE IN FEET
0 500 1000 2000 3000
J.E.EATON U.S.GRANT H.B.ALLEN
1940

FIG. 8

FIG. 9.—Looking northwest across Cone Canyon near boundary between Caliente Mountain and Carrizo Plain. Heavy-bedded sandstone sequence with flows of the "Triple basalt" series near its base, middle, and top is uppermost 800 feet (lower *Baggina robusta* zone) of the true Temblor, which latter has a total thickness of 4,700 feet on the northeast flank of the mountain. Silty sand well below heavy-bedded sequence is in top of *Uvigerinella obesa* zone. Above the upper flow is glimpsed a portion of the soft, partly continental Temblor-Monterey transition, for which see Figure 10.

FIG. 10.—Camera has been turned 90° to right. Looking northeast. Remnant of late Pleistocene fan in immediate foreground. Between this and the dark "Main" basalt flow capping a long strike ridge is the Temblor-Monterey transition; the white, gray, and red partly marine lower portion yields *Turritella carisaensis* var. *padronesensis;* the upper portion (locally talus-covered) is banded red and pink continental sand. Brackish and continental Monterey above the "Main" basalt is hidden except for a barely glimpsed ridge at left margin and hilltop at middle. Hills at edge of Carrizo Plain are continental Pliocene (?), as are those a short distance out in the plain. At far edge of the plain is the long, straight scarp of the San Andreas rift, beyond which looms the Temblor Range.

FIG. 11.—Whiterock Bluff, looking northwest across Cuyama River. Cliff exposes *Valvulineria californica* (lower Monterey) reefy white sand, silt, and diatomite. These beds grade conformably upward to overlying gray and tan sand, visible on right, containing one or more reefs of *Ostrea bourgeoisii*.

mediately east of the line Long Canyon-Cone Canyon, since northwest of these canyons local thrust faults cut out part of the succession. Along the canyons mentioned the lower and middle 3,900 feet of the Temblor is largely buff-weathering coarse to fine sand with local heavy-bedded sandstones and fossiliferous dark brown reefs and large dark brown concretions. The upper 800 feet (Fig. 9) is here chiefly coarse, heavy-bedded gray sandstone. In this upper portion brackish-water and continental beds yielding terrestrial vertebrate remains appear at intervals in the marine succession, and three flows of basalt (the Triple basalt series) ranging from 10 to 30 feet in thickness are present a few hundred feet apart near the base, middle, and at the top of the member.

The two lower of the flows mentioned can be traced southeasterly nearly to Padrones Spring, and the upper one northwesterly to beyond Sulphur Spring, precisely tying in distant areas. The lower two are dense, black basalt, wax and wane in the same directions, die out on the northwest at the same canyon, and truncate only a few feet of strata in a distance of several miles; these two seemingly represent but transient interludes in upper Temblor deposition. The upper flow is dark green, waxes and wanes along its trace in directions opposite to those of the two lower flows, disappears southeast of Leaning House Gap into what appears to be a marked erosional unconformity that causes the middle flow of the Triple basalt series to first converge upon and then diverge from the much younger Main basalt, and seems to uncover additional subjacent strata in the opposite direction (diagonally basinward). These features suggest that it may have followed an appreciable hiatus; that it belongs to a later cycle and is unconformable above the Temblor. On the assumption that the flows thinned more or less radially from a vent, the two lower would seem to have originated several miles northeast, and the upper one several miles north, of the present Wells Ranch.

If a line striking approximately N. 27° W. is drawn through the Cone Canyon area the Temblor will be found to coarsen within a short distance northeast, and become finer-grained within a short distance southwest, of this line. According to this control, almost the entire Temblor becomes sandstone in eastern parts of Caliente Range, with the upper portion becoming pebbly sandstone. Conversely, southwest of this line the Temblor becomes more silty, has fewer heavy-bedded sandstone lenses, and the upper portion which forms a distinct lithologic unit in the Cone Canyon area (Fig. 9) acquires thick brown reefs and large dark brown concretions similar to those in the lower and middle Temblor and merges texturally into the latter.

Near Deadman Flat (extreme northwest corner of Fig. 3) the Temblor overlaps upon Cretaceous(?), and then upon granite. Except for a basal sandstone that yields *Turritella ocoyana* var. *bösei* the Temblor is here largely fine sand and siliceous shale due to being near the axis for finest textures and on the southwest flank of the basin which received relatively little material (Fig. 2).

Temblor of western Cuyama Valley.—As has been mentioned on a previous page, much of the several hundred feet of chocolate to gray silt and silty sand with hard brown reefs mapped for convenience with the upper Vaqueros at and near Taylor Canyon is probably lower Temblor in age. Above this lies soft, pebbly, gray fossiliferous Temblor sandstone previously mentioned. What relation this relatively thin section bears to an adjacent thicker section of Temblor upthrust northeast of the Whiterock fault has not been a matter of investigation.

At Devil's Elbow, south across Cuyama River, chocolate shale, containing dark brown reefs and concretions, that is locally faulted against massive white Vaqueros sandstone and overlain by white siliceous shale, silt, and fine sand apparently represents a thinning edge of the Temblor. West of the region shown on Figure 3 the Temblor, like the Vaqueros, is largely absent, various horizons of the Monterey overlapping upon Cretaceous(?).

Temblor of southwestern Cuyama Valley.—An upper part of the 1,500-foot section of fossiliferous hard, rusty gray and pinkish heavy-bedded sandstone mentioned as cropping out in a window west of Schoolhouse Canyon is inferentially of Temblor age, the rocks being too hard to collect contained pectens that might substantiate such an assignment.

Farther southeast, between Aliso and Pato canyons (south of the area shown in Figure 3), Temblor strata crop out in irregular bands in an area ranging from 1 to 6 miles wide and 20 miles long. The reader is referred to English[35] for a structural and contact map of this area. On his map the Temblor of the present paper is designated as Maricopa shale, and the Monterey as Santa Margarita, age assignments which are indicated to be respectively too young[36] and in part too young. At Bitter Creek the Temblor comprises about 1,000 feet of strandward white and gray reefy sandstone which rests conformably on submassive Vaqueros sandstone and is overlain unconformably by white and

[35] W. A. English, "Geology and Oil Prospects of Cuyama Valley, California," *U. S. Geol. Survey Bull. 621-M* (1916), Pl. XIX.

[36] R. W. Pack, "The Sunset-Midway Oil Field, California," *U. S. Geol. Survey Prof. Paper 116* (1920), p. 28.

tan *Astrodapsis* sands of the Monterey. Southeastward, in Newsome Canyon, the Temblor grades to the more typical buff-weathering gray sandstone and silty sand facies with hard brown reefs and large brown concretions. Still farther southeast it coarsens and acquires non-marine facies as the continental head of Caliente trough is approached.

Differences in aspect between the Temblor and Vaqueros.—Far strandward, both in the district discussed and elsewhere in California, the three major Miocene stages—the Vaqueros, Temblor, and Monterey—tend to be represented by monotonous white and gray sands, and nearly all physical distinctions disappear. Similarly, far basinward (most of the basinward Vaqueros is beneath the sea west of the state) these stages tend to be represented by prevailingly siliceous shales, and nearly all physical distinctions likewise disappear. Between these extremes lies an intermediate belt where each major stage, broadly viewed, has its own characteristic physical aspect. This generality holds true for the district being discussed, which is situated between converging basins.

The Vaqueros of the district is almost universally sand and silty sand of different textures, whereas the Temblor varies from sand to shale. However, Vaqueros and Temblor successions of the same average texture tend to have a different physical aspect, the dividing line coinciding almost exactly with that between the respectively tropical and subtropical faunas. Vaqueros fine sand and silty sand are prevailingly greenish; equivalent textures in the Temblor are prevailingly brown or bluish gray. The medial Temblor abounds in large concretions, which the writers have not observed, even in similar textures, in the Vaqueros. Vaqueros marine sandstones tend to be heavier- and cleaner-bedded than those of the Temblor. They are white, gray, or rusty; scarcely ever brownish as in much of the Tremblor. The Vaqueros as a whole weathers a dark rusty, somewhat banded color; the Temblor an almost homogeneous brown or buff.

The different general aspects mentioned are particularly apparent when looking north from Cuyama Valley at sections on the southeast and northwest ends of Caliente Mountain. For a close view an observer may examine the completely exposed Vaqueros of Caliente scarp, and then, offsetting eastward, examine the well exposed Temblor near the head of Long Canyon and in Cone Canyon. The overlying Monterey of the district is likewise generally distinct. Its marine sands tend to be whiter and less arkosic than those in the Temblor, with locally a faintly greenish cast and a tan-weathering member near the middle. Its hard siliceous and soft diatomaceous shales weather white, an aspect that is rare in even the finest Temblor or Vaqueros.

What controls determined such general differences, widespread in coastal California, are at present unknown. While the more or less regional physical aspects mentioned are but broad generalizations, locally unreliable, which are useful chiefly in the intermediate belt to map disconnected successions whose age has been determined from faunas, their existence explains why geologists who use the Vaqueros, Temblor, and Monterey strictly as faunal stages representing time have for a generation referred to these stages as formations.

FAUNA OF THE TEMBLOR

The change in fauna between Vaqueros and Temblor times is one of the two largest within the Miocene of California, the other major change being that between the Temblor and the Monterey. Of the two, the faunal change at the Vaqueros-Temblor contact appears to be the more abrupt. At Caliente Mountain and elsewhere in the state Vaqueros index species which persisted throughout this stage disappear in a thin transition zone that reflects a regional cooling of waters as an epeirogenic pulsation[37] sent the previously slowly encroaching sea far beyond former boundaries, largely eliminating warm, protected arms, and giving the waters a more arcuate, open aspect. The change in fauna was state-wide, as Loel and Corey[38] have shown from a regional disappearance of uppermost and transitional Vaqueros guides. The Vaqueros fauna at Caliente Range (Fig. 8) checks much of Loel and Corey's zonal succession for the state, the only large difference appearing to be that hardy elements of the superjacent Temblor fauna appear earlier in the Vaqueros at the offshore Caliente Range than Loel and Corey report for elsewhere in California. At the top of the transition zone the last tropical Vaqueros guides disappeared, and the subtropical Temblor fauna moved in and took possession of the strand.

Temblor species collected along the maximum section through Caliente Mountain are listed in Table I. The lower half of the Temblor has been inadequately collected as yet. The Temblor of California has not been monographed (all other post-Oligocene stages have been), with the result that zones of its fauna have not been established. If and when the stage is monographed it is suggested that Caliente Mountain be considered as a control section for the titular head of its fauna, for not only does the *Turritella ocoyana* clan make its earliest known

[37] J. E. Eaton, "Tie-Ins between the Marine and Continental Records in California," *Amer. Jour. Sci.*, Vol. 237, No. 12 (December, 1939), Fig. 1.

[38] Wayne Loel and W. H. Corey, "The Vaqueros Formation, Lower Miocene of California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 22, No. 3 (1932).

appearance here, but its two chief varieties can be found almost continuously through 6,800 feet of upper Vaqueros and Temblor in a superposition which is absolute, and lesser variants seem to be present which might make possible a zoning similar to that for the *Turritella inezana* clan in the Vaqueros.

The exposed Temblor is fossiliferous here and there throughout the district, but fossils are vertically persistent and abundant only in the optimum belt that strikes diagonally through Caliente Mountain (Fig. 2), having elsewhere the usual California arrangement of a few productive horizons separated by hundreds or thousands of feet of nearly barren strata.

Occasional sampling, by the writers and others, for Foraminifera in the Temblor has permitted horizons of the (reading downward) lower *Baggina robusta*, *Uvigerinella obesa*, and *Plectofrondicularia miocenica* zones of upper, middle, and late lower Temblor age to be locally indicated on Figures 3 and 8, but except in the Morales syncline this sampling has been too intermittent to determine precise boundaries for these zones. The early lower Temblor has not been sampled. Future workers are not expected to find good foraminiferal samples northeast of a line striking about N. 27° W. from Ernest's Canyon, due to the prevailing coarseness of strata on the northeast. The best and most consecutive Temblor foraminiferal faunas will presumably be found on the flanks of the long Morales syncline, which extends northwest from Scarp Canyon to beyond a point opposite Deadman Flat. The most valuable samples for tying in with the Mollusca will come, however, from the sparsely foraminiferal Temblor between Ernest's Canyon and Midway Canyon on the northeast flank of Caliente Mountain, where patience and tenacity will be required.

Dougherty[39] has described terrestrial vertebrate faunas from beds mapped by the present writers as upper Temblor and transitional Temblor-Monterey several miles east of Cone Canyon that are associated with the "Triple basalt" flows. The latter precise markers show that some of these vertebrate horizons correspond closely with upper Temblor marine invertebrate horizons $17\frac{1}{4}$ and 18 (see Table I), and others with overlying strata, in this canyon (Table I and Fig. 8). He lists two species of *Merychippus*, together with *Parahippus?*, *Hypohippus?*, *Merychyus*, *Ticholeptus?*, *Dromomeryx?*, *et cetera*.

The oyster listed by Dougherty from the upper Temblor as *Ostrea vespertina loeli* is not that form, but is *O. altatemblorensis*. Heavy faulting in the Padrones Spring area together with an occurrence there of

[39] J. S. Dougherty, "A New Miocene Mammalian Fauna from Caliente Mountain, California," *Carnegie Inst. Washington Pub. 514* (1940), pp. 109–43.

abundant *Turritella carisaensis* var. *padronesensis* stratigraphically and directly below C.I.T. loc. 312 suggests local duplication in the section and the possibility that the Lower basalt may be at or near the horizon of one of the Triple basalts of the west; that is, it is not at present certain that any of the terrestrial vertebrate remains collected by Dougherty are older than marine invertebrate horizon 18 which is early upper Temblor. C.I.T. localities 315 and 324 are upper Temblor according to the mapping of the present writers. C.I.T. localities 312, 313, 322, and 323 are in an early part of the transitional Temblor-Monterey of the writers, not in their upper Temblor as stated by Dougherty through a misunderstanding. The apparent erosional unconformity previously mentioned as causing an erratic convergence of horizons separates the two sequences and here coincides with a marked change between their respective marine invertebrate faunas. It is thus important that terrestrial vertebrate collections from the upper Temblor and from the Temblor-Monterey transition be segregated, and, when sufficient material has been collected, be compared and correlated separately with terrestrial vertebrate faunas elsewhere.

Ecology.—Ecologic aspects, while present in the true Temblor of the district, are apparently less radical than those in the underlying Vaqueros, presumably in part because the more open, arcuate Temblor sea seemingly lacked the marked contrast between a narrow central channel and a fringe of shallow, warm arms that existed in Vaqueros time as the Caliente embayment progressively transgressed laterally upon lowlands inherited from the Oligocene.

MONTEREY (UPPER MIOCENE)

Type and history of the term.—The earliest published use of the term Monterey in connection with a stratigraphic sequence appears to have been that by Blake[40] in 1855 for deposits near the town of Monterey. The typical area was outlined and clarified by Hanna[41] in 1928. As the first name applied to Miocene strata in California, the term Monterey takes precedence over all others.

The facts that the stratigraphic limits of the type Monterey, whose base where exposed rests unconformably on Santa Lucia quartz diorite, are almost exactly equivalent to those of the upper Miocene unit

[40] W. P. Blake, "Notice of Remarkable Strata Containing the Remains of Infusoria and Polythalmia in the Tertiary Formation of Monterey, California," *Proc. Acad. Nat. Sci.* (Philadelphia), Vol. 7 (1855), pp. 328–31.

[41] G. D. Hanna, "The Monterey Shale of California at Its Type Locality with a Summary of Its Fauna and Flora," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 10 (October, 1928), pp. 969–85.

of California and that no strata of Temblor (middle Miocene) or of Vaqueros (lower Miocene) age are exposed at the type, remained unknown for more than 70 years after the typical description. In this lack of knowledge the feature that siliceous and diatomaceous shales are prominent in the typical Monterey led some workers to apply the term Monterey to any such shales in the Miocene, and occasionally to such in the Eocene, Upper Cretaceous, and Pliocene. However, even in these early days various paleontologists including Ralph Arnold and F. M. Anderson correctly restricted the term Monterey to the upper Miocene unit as this is now known, although where faunas were inadequate they did not always do so, and owing to the sparse megafauna at the type Monterey they could not conclusively prove the correct assignments when these were made.

In 1928 the senior writer of the present paper collected foraminiferal samples from the type Monterey, securing good faunas from basal strata within a few feet of the underlying quartz diorite, and also from the highest member. Equal parts of each sample were given to all professional micropaleontologists then practicing in Southern California. These workers agreed that the lowest foraminiferal samples represented the *Valvulineria californica* zone, and the highest ones what has subsequently become known as the *Nonion schencki* zone, of the upper Miocene. This revealed that the stratigraphic limits of the type Monterey are essentially synonymous with those of the upper Miocene unit of California, and that the type exposes no strata older than this unit. In 1931 Galliher[42] published a paper on the type Monterey which confirmed the data mentioned, and in which he listed intermediate zones. Other research has shown that the type Temblor is overlain by several hundred feet of strata yielding a Temblor-Monterey transitional fauna, which, in turn, is overlain by the *Valvulineria californica* zone. There is thus no conflict between the type Temblor and the type Monterey, which represent completely different, successive horizons.

For a number of years it was believed that a coarse strandward upper Miocene succession called San Pablo (reading upward, the Briones, Cierbo, and Neroly[43] substages) was stratigraphically above the fine-grained basinward Monterey. Since the type Monterey includes the

[42] E. W. Galliher, "Stratigraphic Position of the Monterey Formation," *Stanford Univ. Micropaleontology Bull.*, Vol. 2, No. 4 (1931), pp. 71–74.

[43] The term Neroly was proposed by Clark in 1929 as the formal name for the upper, unconformable unit of the San Pablo (Merriam, 1898), previously designated merely as "upper San Pablo." The Neroly substage is equivalent to the typical Santa Margarita (Fairbanks, 1904), which latter term has sometimes been incorrectly used to include horizons and faunas of Cierbo and even Briones age that over much of the state lie unconformably below the typical horizon.

highest known Miocene of California, it has been apparent for some time that these other deposits represent coarse, strandward facies of much or all of the Monterey, although precise zonal equivalencies are still a matter of investigation.

To summarize, the Monterey at its type is exclusively the upper Miocene unit of California, the lower and upper boundaries of this type happily coinciding almost exactly with those of a major natural unit generally considered to be of this age, and does not include transitional Temblor-Monterey horizons which are elsewhere represented in the state (Fig. 8). Though it represents a period of maximum deposition of silicious and diatomaceous shales basinward in California and is famous for this reason, the Monterey grades strandward to sandstone, being indicated to contain in this direction a larger cubic content of coarse material than does any other major Miocene stage. Monterey time is characterized by a foraminiferal fauna ranging from the *Valvulineria californica* to the *Nonion schencki* zones, inclusive. Lower and higher horizons which tend to grade faunally into subjacent and superjacent stages and which are not known to be present at the type are sometimes assigned to this stage, in which latter case they are commonly termed transitional, as in the present paper.

Temblor-Monterey transition.—In parts of California the Monterey rests unconformably on the Temblor due to diastrophism which was marked on the edge of basins but almost imperceptible near their centers. In such areas the two stages are usually distinct. The unconformity, where present, varies in amount from place to place. Thus, in the eastern Santa Monica Mountains upper portions of the *Baggina robusta* zone and all of the *Valvulineria californica* zone are locally absent. In Cuyama Valley it is chiefly upper parts of the *B. robusta* zone that are missing; on the southwestern flank of Caliente Range deposition was seemingly continuous and entirely marine; on the northeast flank of this range what appears to be an upper part of the *B. robusta* zone is largely continental, and so on. As an average for all basins the time of maximum emergence of California seems to have corresponded with early upper parts of the *Baggina robusta* zone, with the result that this fauna may locally be found, where the unconformity is minor, both below and above a physical break. Upper parts of the zone are a horizon of faunal transition between the Temblor and the Monterey, the two faunas having proportions which vary according to local ecologic conditions, with here one fauna dominating, and there the other. Due to local ecologic factors a premature Monterey fauna locally begins slightly below the physical break and a relic Temblor fauna locally persists slightly above it..

Near the center of deep basins deposition was continuous, and all zones may be present including the faunal transition. In the transitional horizon the foraminiferal fauna is intermediate between those of the Temblor and the Monterey, tending to most resemble the former in shallow, warmer waters, and the latter in deeper, cooler ones. The megafauna reveals similar relations, Temblor mollusks surviving in warm, protected bays and inlets at the same time that Monterey forms were appearing in open, cooler waters. The physical aspects also tend to be intermediate, locally most resembling one and locally the other stage, but being in the great majority of cases nearest the Monterey. The varying fauna of the transition zone has given rise to controversy in western San Joaquin Valley regarding the stage to which these strata, locally absent due to unconformity, properly belong. They would appear to belong not certainly to any distinct stage, but to lean here one way, and there another. For example, in deeper, cooler waters as at Carneros Creek the fauna seems most allied to that of the Monterey, whereas in shallower, warmer waters as near Coalinga it seems most allied to that of the Temblor.

Caliente trough presents most phases of the problem, the transitional horizon being represented, as stated, in the continuously deposited section on the southwest flank of this range by a wholly marine and seemingly complete transitional succession, and in strandward portions of Cuyama Valley and Carrizo Plain by a locally variable degree of unconformity. The lower part of the *Baggina robusta* zone yields a purely Temblor molluscan fauna in all areas of the district, in all known districts of California, and apparently represents the uppermost or Button Bed member of the type Temblor. Wherever definitely present in the state it appears to be below the horizon of maximum unconformity. There thus seems to be every good reason for regarding this part as upper Temblor. The upper part of the *Baggina robusta* zone, on the other hand, seems to yield Monterey mollusks basinward and Temblor mollusks strandward; in southeastern Caliente Range the so-called *Turritella ocoyana* fauna, continuous for 4,700 feet, apparently stops either without entering or shortly after entering the transitional horizon, being replaced by *Turritella carisaensis* var. *padronesensis*, whereas along the warm southern fringe of Cuyama Valley a relic *T. ocoyana* fauna continues upward, through the transitional portion, into the lower Briones of true lower Monterey age. Thus, in the upper *Baggina robusta* (transition) horizon there seems to be locally either a Temblor, a Monterey, or a mixed faunal assemblage according to local ecologic factors.

In Figures 3 and 8 the transitional strata are shown as basal Mon-

terey because over most of the district their fauna leans toward the Monterey, and they are physically like the sediments of this stage and quite unlike those of the true Temblor below. It is to be remembered, however, that these strata locally yield a Temblor molluscan assemblage along warm fringes of the trough, and are really transitional.

The two major faunal transitions of the district occasioned by locally different ecologic factors, the Vaqueros-Temblor and the Temblor-Monterey, occur at much the same localities. As regards both, the warm strandward fringe seems to have been the habitat of a pure, older type of fauna at the time that a new fauna was appearing basinward in open, cooler, but not necessarily deeper waters at the same horizon. The two transitions differ in but one observed phenomenon: in the Vaqueros-Temblor relations the physical and faunal aspects tend more toward the older stage, whereas in Temblor-Monterey relations they tend more toward the younger one.

Monterey of the Morales syncline.—The Morales syncline, traceable along the southwest flank of Caliente Range from near the mouth of Scarp Canyon northwest to and beyond the edge of Figure 3, affords the largest single area of exposed Monterey in the district discussed. The Monterey of this syncline seems to be entirely marine except for the uppermost 165 feet, in which wedges of barren pinkish sand alternating with fossiliferous white reefs suggest intermittent brackish conditions and approaching emergence.

The best place for locally studying the transitional and lower Monterey sequence is Section Canyon between the Caliente Mountain and the Morales faults, where a vertical section of the complete *Baggina robusta* and *Valvulineria californica* zones that approximates 2,500 feet in thickness has been measured and sampled foraminiferally. Here, above thick basic sills at the top of the *Uvigerinella obesa* zone that cross Section Canyon near its junction with Pinnacle Canyon, is 650 feet of upper Temblor (lower *Baggina robusta* zone) buff and dark sandy silt with brown reefs and sandstones, then 1,000 feet of chocolate clayey and platy transitional silt carrying yellow reefs (upper *Baggina robusta* zone), then 850 feet of *Valvulineria californica* white sand and sandy silt with pale greenish tints and pearl-colored reefs, and finally 300 feet of brown and white sandstone whose horizon yields the Cierbo and Briones form *Ostrea bourgeoisii* near by. This is a seemingly conformable sequence, terminated at its top by the Morales thrust fault across which is steeply tilted Pliocene(?) pebbly sand.

More fossiliferous sections of the Monterey are obtainable on the opposite side of the syncline, in and near the lower part of Morales Canyon. The oldest beds exposed in the cliff-face between the mouth of

Morales Canyon and Whiterock Bluff are approximately 200 feet of platy chocolate shales and silts with yellow reefs containing the transitional upper *Baggina robusta* fauna. These are here overlain by about 600 feet of *Valvulineria californica* diatomite, clay shale, and reefy sand that contains pearl-colored reefs and weathers white (cliff, Fig. 11). This grades conformably upward, through 40 feet of silty chocolate sand, to 310 feet of tan and gray sand containing one or more reefs of *Ostrea bourgeoisii*. Next above is 200 feet of gray reefy sand containing *Lyropecten* and other mollusks. Unconformably above this is from 155 to 185 feet of Neroly pink sand with white reefs yielding *Ostrea titan* s.s. and abundant pelecypods, the thickness of this member varying due to unconformities which bound it below and above. Continental Pliocene(?) composed largely of angular white siliceous shale pebbles and containing worn, redeposited Monterey oyster shells rests unconformably on the Neroly substage, these continental beds locally having a basal conglomerate composed of blocks of Monterey limestone.

Monterey of the Wells Ranch syncline.—The basic flows and sills closing Temblor time mark the advent of dominantly non-marine deposition along what is now the northeastern flank of Caliente Range. The so-called *Turritella ocoyana* fauna there present throughout 4,700 feet of Temblor has not been observed by the writers above the strata assigned to this stage. The upper Temblor or lower *Baggina robusta* zone (Fig. 9) is followed by 1,300 feet of white, pink, and red non-marine sandstone with interbedded thin marine layers containing *Turritella carisaensis* var. *padronesensis*. Near, but not at, the top of the reddish series is a prominent basalt flow (the "Main" basalt) averaging 60 feet in thickness (Fig. 10). Above the reddish series are 425 feet of thin-bedded, greenish, in part ripple-marked sandstone, then 125 feet of maroon sand, followed by 450 feet of fine, white, brackish-water silty sand containing pearl-colored reefs, this tripartite series being possibly a correlative of the *Valvulineria californica* zone. Still higher are 1,200 feet of coarse salmon and white probably non-marine sandstone locally containing pebble layers and redeposited Temblor oyster shells in its base, and then 1,000 feet of fine to medium light sand and greenish silty sand, also seemingly non-marine. Above this last are continental white, gray, and pink pebbly sands tentatively mapped as Pliocene(?).

Northwest of the above maximum section measured along the line of Cone Canyon the exposed Monterey becomes thinner, and marine phases increase. There are some indications that discontinuities increase in this direction, possibly at the base of the reddish series and

at the top of the superjacent white silty series, which would not be surprising in considering the dominantly continental composition of the local Monterey sequence. Easterly from the maximum section the exposed Monterey becomes thinner and more continental.

Only indeterminate faunas have been found above the lower 500 feet of the reddish series in the Wells Ranch syncline. In the lower 500 feet of reddish beds overlying the Temblor the one determinable species that is locally abundant is *Turritella carisaensis* var. *padronesensis*, which occurs in a few thin marine calcareous layers interbedded with the continental deposits. In southern Cuyama Valley *T. carisaensis* s.s., apparently a much later form, occurs in strata which are definitely Neroly in age. Since these two different forms have not been found in sequence, they are only probably, not certainly, from different horizons. Because continental conditions in the Wells Ranch syncline begin as wedges in the known upper Temblor, because this upper Temblor, the red belt above it, and the flows in both occur as long, narrow bands, because the post-Temblor—pre-Pliocene(?) sequences of the Morales and Wells Ranch synclines have a somewhat parallel aspect, and because the late R. D. Reed informed the writers that he observed the ranges of *T. ocoyana* and of *T. carisaensis* var. *padronesensis* to overlap near Sulphur Spring, the writers tentatively infer a nearly complete Monterey column in Figures 3 and 8 and in Table II. If, on the other hand, as is possible, the definite Neroly occurrence in southern Cuyama Valley of *T. carisaensis* s.s. represents the total range for this entire species, then the lower and middle Monterey are absent in the Wells Ranch syncline, the redbeds there are Neroly resting on Temblor with major unconformity, and the seeming similarity of parts of the post-Temblor sequence in this syncline to the known sequence in the Morales syncline is only a deceptive coincidence.

Table II indicates some relations between the Monterey and the upper and middle Temblor in four parts of Caliente Range from southwest to northeast; from finer to coarser and thicker deposition. The two columns on the left represent the marine Morales syncline, and the two on the right the partly non-marine Wells Ranch syncline. The Temblor equivalencies shown are generally demonstrable across all four columns. For reasons given in the preceding paragraph, the correlation of the marine Monterey in the two columns on the left with the largely non-marine Monterey in the two columns on the right is not certain.

Monterey of western Cuyama Valley.—The Monterey originally extended as a sheet over most of western Cuyama Valley, but is now largely eroded there. Except at Devil's Elbow where 285 feet of transi-

TABLE II

Whiterock Bluff	*Section Canyon N.E. of Morales Fault*	*Sulphur and Goat Springs*	*Cone Canyon Vicinity*	
185 ft. wh. and pink sd. *Ostrea titan*	(Faulted out)			
200 ft. gray, reefy sd. *Lyropecten*			1,200 ft. coarse salmon to wh., pebbly ss.	
310 ft. tan and gray sd. *O. bourgeoisii*	300 ft. coarse brown and wh. sd.			
Valv. calif. 600 ft. diatomite and clay shale. Pearl reefs grading down to yellow	*Valv. californica* 850 ft. fine wh. to pale green sd. and silt. Pearl reefs grading down to yellow	(Eroded) / Wh. sd. silty near top	1,000 ft. fine wh. gypsiferous silty sd. overlying greenish ss. Pearl and yellow reefs	
Baggina rob., upper. 200 ft. chocolate platy shale. Yellow reefs	*Bag. robusta*, upper. 1,000 ft. chocolate clayey and platy shale. Yellow reefs	1,100 ft. red, pink, and wh. non-marine ss. with marine layers	1,300 ft. Red ss. — Flow — Red, pink, and wh. non-marine ss. with marine layers	*Turritella carisaensis* var. *padronesensis*
(Unexposed) MONTEREY				
		— Flow —	— Flow —	
TEMBLOR	*Bag. robusta*, lower. 650 ft. buff and dark sandy shale, and ss. Brown reefs	*Bag. rob.*, lower. 700 ft. buff sandy silt and ss. Brown conc. reefs	Lavender pebbly. 800 ft. Buff conc. sd. Gray to wh. ss.—Flow—Gray ss., buff sd.	
	— Sill —		— Flow —	
	Main Canyon Sills in silt and ss. / Pinnacle Canyon	Silt and ss. with thick brown reefs	*Uvigerinella obesa.* Ss. and silty sd. Brown reefs and concretions	*"Turritella ocoyana* fauna"
	U. obesa Ss. and silt Brown reefs / (Cut out by Caliente Mt. thrust fault)	Ss. with brown reefs	Ss. with brown reefs	
	Silt and ss.	*Plecto. miocenica.* Ss. and silt	Ss. and silty sd.	

tional Monterey (upper *Baggina robusta*) and (or) lower Monterey (*Valvulineria californica*) platy white siliceous shale and tuffaceous sand rests on an equally thin section of Temblor, near the mouth of Carrizo Canyon where Monterey is faulted against upper Vaqueros,

and at isolated points along the southern edge of the valley, Monterey strata have not been observed to crop out in the western portion of Cuyama Valley illustrated in Figure 3. West of this figure a hundred feet or so of fossiliferous lower Neroly white sands variously overlap or are faulted against Vaqueros and Cretaceous(?) for several miles north of Cuyama River. These sands, containing thick reefs of *Ostrea titan* s.s., are overlain by several hundred feet of middle Neroly shale with interbedded fossiliferous sands, and this, in turn, by pinkish, apparently non-marine sands of undetermined relations and age. South of Cuyama River a more nearly complete succession of the Monterey is present, a fauna ranging from *Astrodapsis brewerianus* s.s. upward to *A. schencki* var. *mirandaensis* having been secured immediately west of the territory illustrated in Figure 3.

Structural change in Monterey time.—Before proceeding further it is desirable to emphasize that, in the part of Caliente trough made the subject of this paper, marked trough conditions with resulting extreme thicknesses of sediment existed only to or near the time of deposition of the *Valvulineria californica* zone; at or near this time the dynamic curve flattened, apparently without immediately interrupting the continuity of marine deposition, subsequent deposits being relatively coarse and having more nearly equal thicknesses over the district. Miocene thicknesses prior to this change are twice or more the average for California, whereas those subsequent to it tend to be somewhat less than average for the state, which represents a swing to the opposite trend. Such a change, in one direction or the other, has been observed at or near this horizon at many places in the Miocene series of California. Although sections revealing a somewhat uniform subsidence throughout the epoch are not uncommon in the state, in the great majority of sections if the Vaqueros and Temblor are thick the Monterey is relatively thin, or if the two lower stages are thin then the Monterey is relatively thick. In Figure 8 the three left-hand columns illustrate one, and the three right-hand columns the other, of such relations above and below the *Valvulineria californica* zone.

The feature that the rearrangement in dynamics being discussed is expressed as a (seemingly) haphazard exchange of structural values between adjacent areas over much of California, a mere trading between neighbors that apparently involved no major change in the regional fauna or in the total extent of seas, suggests that the cause was provincial and not epeirogenic. The true epeirogenic controls inaugurating the Vaqueros, Temblor, and Monterey stages sent the sea ponderously in one general direction and caused major changes in the megafauna; they appear to be quite different from a rearrangement

of local structure and facies to which the regional fauna could become adjusted by moving here and there a few miles as it did during this particular change. The particular phenomenon seems to have involved chiefly a rearrangement of local pressures and attendant local values in coastal California with little change in averages and totals for the province. The writers have been intrigued by the fact that the earliest known occurrence of the San Andreas rift as a continuous line of adjustment was in or about early upper Miocene, which, whether it be significant or only a coincidence, approximates the inception of rearranged local pressures in the Miocene of coastal California. The inception of marked movement along the great San Andreas rift, which is the line of maximum horizontal adjustment in California, must have profoundly affected the distribution of compression and tension in coastal parts of the state, and if it could be proved to have been coincident with the rearrangement of pressures described would appear to have been an adequate cause for the latter. However, since the mentioned date for inception of the rift is only the earliest known, and not necessarily the actual date, the cause of the general rearrangement of local pressures which occurred in California in or about *V. californica* time is at present speculative.

During the Vaqueros and Temblor a triangular area roughly between the present Whiterock and Cuyama faults was relatively resistant to depression, and, as shown by its thin sediments, separated a secondary, lesser trough southwest of Cuyama River from the main trough along what is now Caliente Range. In Monterey time, due apparently to orogenic changes between the Temblor and Monterey, this division into a primary and a local secondary trough was greatly accentuated. The triangular area seems to have become in part an emergent peninsula, and the secondary trough, traceable along the entire southwestern part of what is now Cuyama Valley, rivalled the main trough in subsidence and in its thickness of acquired upper Miocene sediments. Subsequent to the *Valvulineria californica* zone the local marine record is best preserved in the secondary trough owing to the post-Temblor encroachment of continental fill southwestward across the present Carrizo Plain and much of the main axis for subsidence (Fig. 4). The latter phenomenon shifted the chief faunal record from Caliente Range to southwestern Cuyama Valley, where is found the superb *Astrodapsis* and *Ostrea* succession of the upper Miocene.

Monterey of southwestern Cuyama Valley.—In eastern branches of Deadman Canyon pre-Monterey rocks of undetermined age are overlain with 30° or more of angular unconformity by a fossiliferous basal sandstone containing a *Turritella ocoyana* fauna, and then 355 feet of

white siliceous shale, silt, and sand resembling the similar thickness of transitional Monterey (upper *Baggina robusta*) and (or) lower Monterey (*Valvulineria californica*) at Devil's Elbow. Next above, 365 feet of soft gray and tan sand occupies the position of the Cierbo substage and yields *Ostrea cierboensis?* in place. In the main canyon a reef of *Ostrea titan* s.s. occurs about 100 feet higher in the base of 300 feet of gray silty sand containing pelecypods which is followed, in turn, by several hundred feet of unfossiliferous gray, yellow, and faintly pinkish silty sand that appears to be non-marine. Future workers are cautioned against abundant *Ostrea titan* fragments which in eastern branches drift down and lie deceptively near reefs where only the older form *O. cierboensis?* occurs in place.

At and near Bitter Creek (Figs. 2 and 8) occurs the echinoid optimum previously mentioned. The optimum belt is a narrow band less than ½ mile wide that can be traced for about 6 miles between Aliso and Salisbury canyons. Basinward from this narrow band the Monterey becomes more silty and is almost barren of echinoids, though mollusks are present. The optimum belt resulted from peculiarly favorable local conditions that prevailed here during the Monterey. In Vaqueros time a side arm of Caliente trough existed at and near Montgomery Potrero, southerly from the subsequent echinoid optimum. In this arm was deposited much coarse, white, submassive Vaqueros sand which became emergent near the beginning of Monterey time and was redeposited during this latter stage in what must have been clear waters lying off a broad beach that perhaps rivaled anything that exists in California to-day. The echinoids occur abundantly in the coarser, cleaner strata, intervening silty layers being largely barren except for local reefs of *Ostrea*.

In the vicinity of Bitter Creek (Figs. 12 and 13) the Monterey ranges from 2,350 to 2,700 feet in thickness according to the local magnitude of unconformities below, above, and within it. Unconformity with the underlying Temblor is suggested by the feature that in the westernmost branch of Bitter Creek coarse, basal Monterey rests on about 75 feet of thin-bedded *Baggina robusta* silt, a few hundred yards easterly on submassive sand, and ½ mile easterly on heavy-bedded gray sandstone; however, the possibility of this being a thrust contact on the west has not been eliminated. In this distance easterly approximately 150 feet of additional Monterey strata seem to be present above the supposed unconformity which are absent on the extreme west.

The lowest Monterey present—lower Briones white, reefy sands which occur in the easternmost branch of Bitter Creek—has yielded

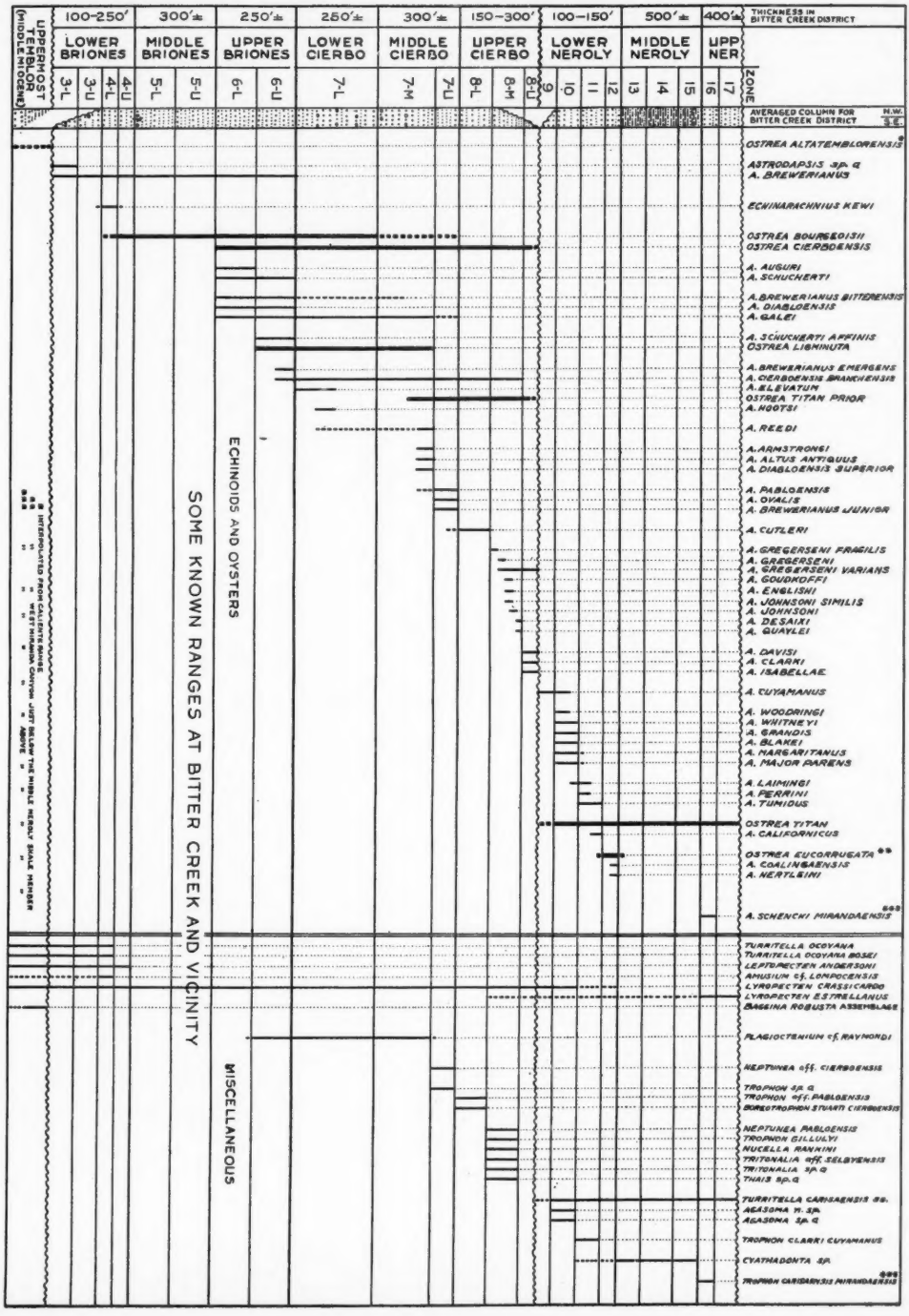
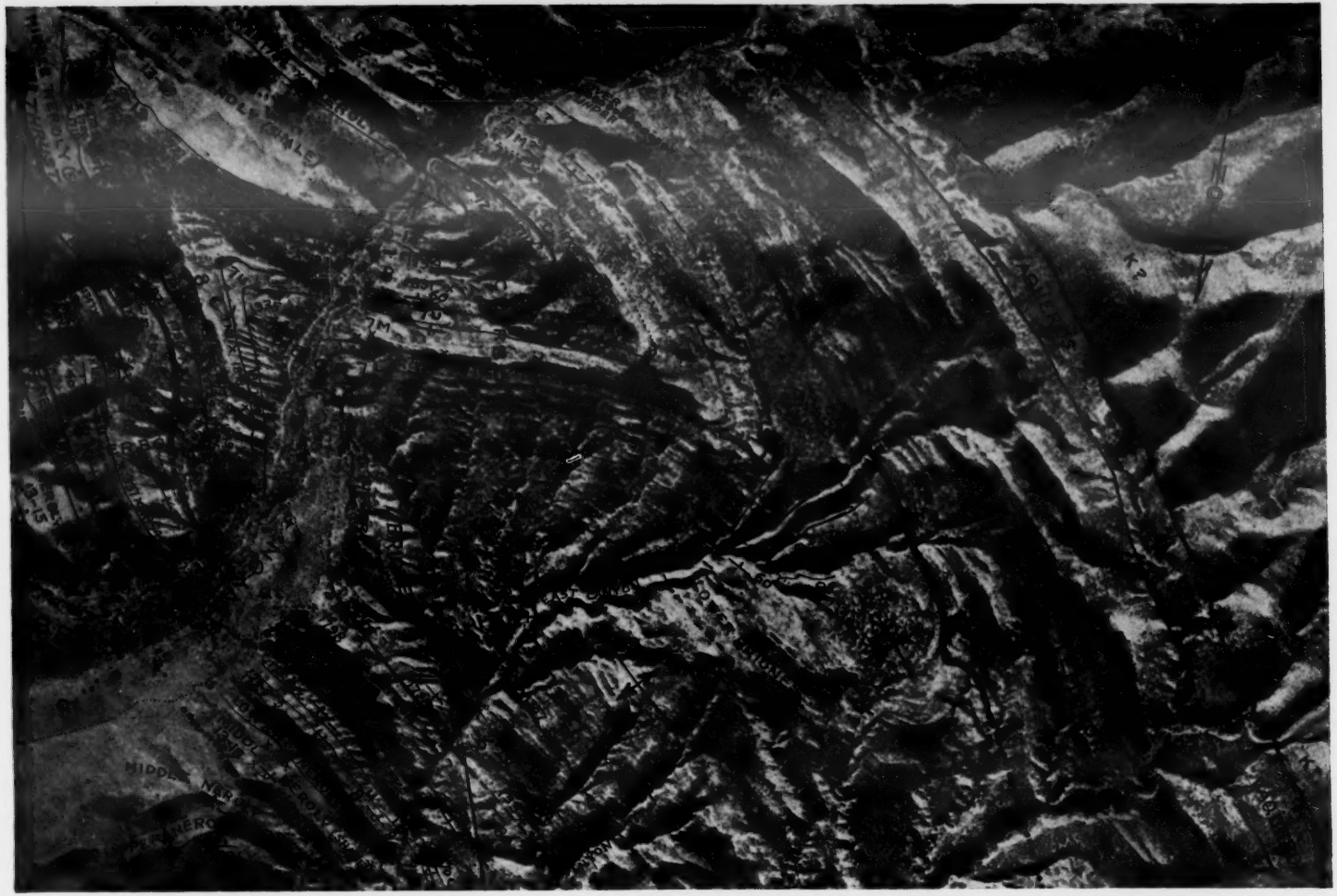

UPPERMOST TEMBLOR (MIDDLE MIOCENE)
100-250'
LOWER BRIONES
300'±
MIDDLE BRIONES
250'±
UPPER BRIONES
250'±
LOWER CIERBO
300'±
MIDDLE CIERBO
150-300'
UPPER CIERBO
100-150'
LOWER NEROLY
500'±
MIDDLE NEROLY
400'±
UPPER
THICKNESS IN BITTER CREEK DISTRICT
ZONE
AVERAGED COLUMN FOR BITTER CREEK DISTRICT
N.W.
S.E.
3-L
3-U
4-L
4-U
5-L
5-U
6-L
6-U
7-L
7-M
7-U
8-L
8-M
8-U
9
10
11
12
13
14
15
16
17
OSTREA ALTATEMBLORENSIS*
ASTRODAPSIS sp. a
A. BREWERIANUS
ECHINARACHNIUS KEWI
OSTREA BOURGEOISII
OSTREA CIERBOENSIS
A. AUGURI
A. SCHUCHERTI
A. BREWERIANUS BITTERENSIS
A. DIABLOENSIS
A. GALEI
A. SCHUCHERTI AFFINIS
OSTREA LIGNINUTA
A. BREWERIANUS EMERGENS
A. CIERBOENSIS BRANCHENSIS
A. ELEVATUM
OSTREA TITAN PRIOR
A. HOOTSI
A. REEDI
A. ARMSTRONGI
A. ALTUS ANTIQUUS
A. DIABLOENSIS SUPERIOR
A. PABLOENSIS
A. OVALIS
A. BREWERIANUS JUNIOR
A. CUTLERI
A. GREGERSENI FRAGILIS
A. GREGERSENI
A. GREGERSENI VARIANS
A. GOUDKOFFI
A. ENGLISHI
A. JOHNSONI SIMILIS
A. JOHNSONI
A. DESAIXI
A. QUAYLEI
A. DAVISI
A. CLARKI
A. ISABELLAE
A. CUYAMANUS
A. WOODRINGI
A. WHITNEYI
A. GRANDIS
A. BLAKEI
A. MARGARITANUS
A. MAJOR PARENS
A. LAIMINGI
A. PERRINI
A. TUMIDUS
OSTREA TITAN
A. CALIFORNICUS
OSTREA EUCORRUGATA**
A. COALINGAENSIS
A. NERTLEINI
***
A. SCHENCKI MIRANDAENSIS
ECHINOIDS AND OYSTERS
SOME KNOWN RANGES AT BITTER CREEK AND VICINITY
MISCELLANEOUS
TURRITELLA OCOYANA
TURRITELLA OCOYANA MOSSI
LEPTOPECTEN ANDERSONI
AMUSIUM cf. LOMPOCENSIS
LYROPECTEN CRASSICARDO
LYROPECTEN ESTRELLANUS
BASSINA ROBUSTA ASSEMBLAGE
PLAGIOCTENIUM cf. RAYMONDI
NEPTUNEA aff. CIERBOENSIS
TROPHON sp. a
TROPHON aff. PABLOENSIS
BERETROPHON STUARTI CIERBOENSIS
NEPTUNEA PABLOENSIS
TROPHON GILLULYI
NUCELLA RANKINI
TRITONALIA aff. SELBYENSIS
TRITONALIA sp. a
THAIS sp. a
TURRITELLA CARISAENSIS ss.
AGASSIA n. sp.
AGASSIA sp. a
TROPHON CLARKI CUYAMANUS
CYATHADONTA sp.
***
TROPHON CARISAENSIS MIRANDAENSIS
* INTERPOLATED FROM CALIENTE RANGE
" " WEST MIRANDA CANYON JUST BELOW THE NIBBLE NEROLY SHALE MEMBER
" " " ABOVE " " " "

FIG. 12


MIDDLE
MIDDLE NEB
PLATTSMOUTH

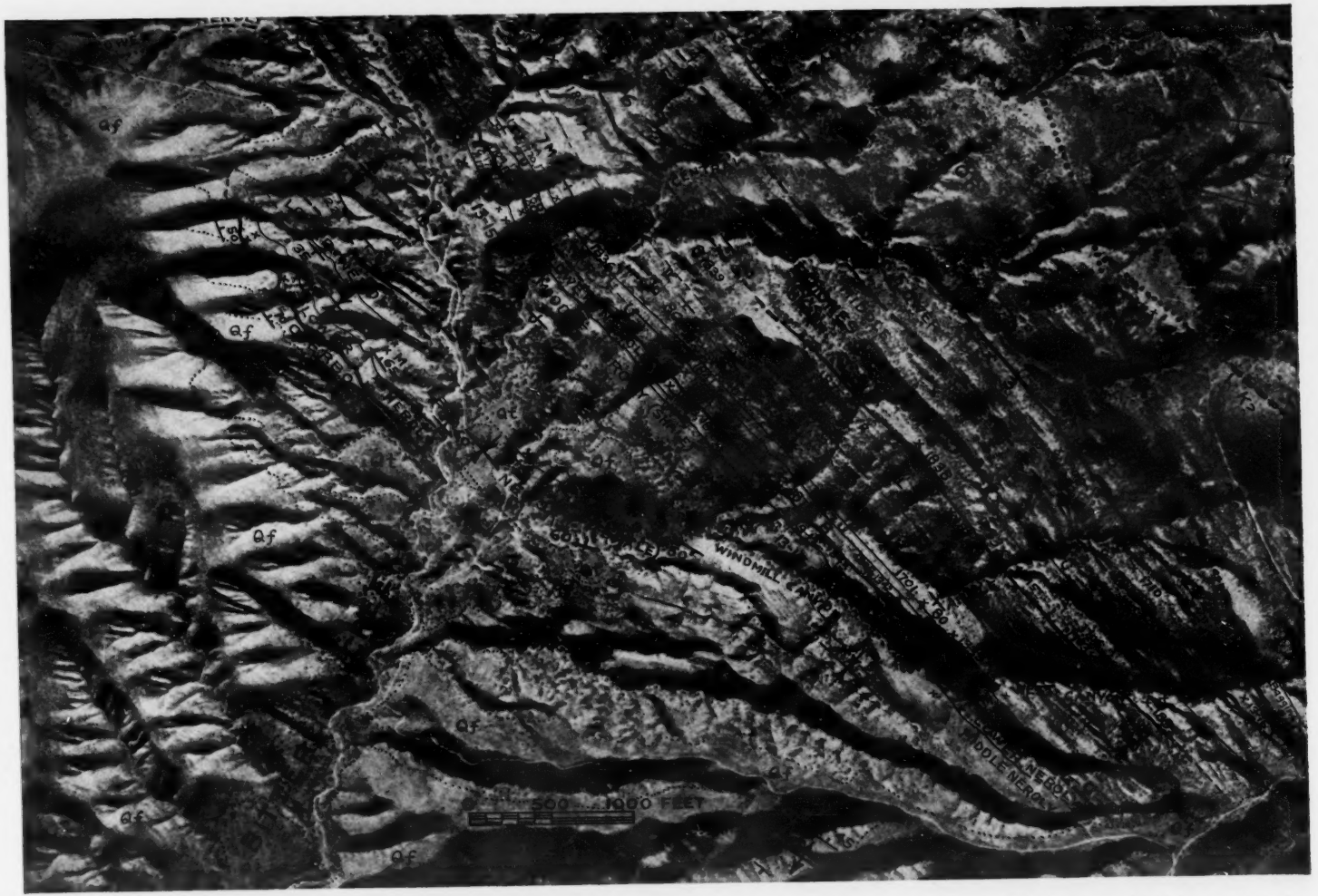

Qf
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FIG. 14.—Part of zone 8-U (late upper Cierbo) near head of Discovery Gulch, just below Cierbo-Neroly unconformity. The echinoids in the photograph are chiefly *Astrodapsis davisi*, with some *A. clarki*, and occasional *A. gregerseni* var. *varians*. This zone, here about 25 feet thick, is largely composed of astrodapses in approximately the abundance illustrated.

Astrodapsis brewerianus and *Ostrea bourgeoisii*, together with poorly preserved specimens of a more advanced, elongate, higher-petaled species of *Astrodapsis*. These forms are associated with *Turritella ocoyana* var. *bösei*. About 150 feet higher is a relic *Turritella ocoyana* fauna which includes *T. ocoyana*, *T. ocoyana* var. *bösei*, *Leptopecten andersoni*, and *Amusium lompocensis?*. Where the beds containing this relic fauna become basal farther west due to overlap they include reefs of *Echinarachnius kewi*, a gigantic new species four or more inches in diameter known only from this lower Briones horizon. The foregoing faunas occupy 100–250 feet of strata according to the local magnitude of the subjacent unconformity and (or) thrusting on the west.

Resting on the lower Briones with apparent conformity and gradational aspect, though the contact is not sufficiently well exposed to be sure of its nature, is about 300 feet of middle Briones fine to medium gray and tan reefy sand containing *Ostrea bourgeoisii*. Next above is approximately 250 feet of medium-grained upper Briones reefy sand which has yielded *O. bourgeoisii*, *Astrodapsis brewerianus*, *A. diabloensis*, and six new species and varieties of *Astrodapsis*. *O. cierboensis* has been collected from near the base, and *O. ligminuta* from near the top, of this member.

Conformably above the foregoing is 700–850 feet, depending on the magnitude of an unconformity at the top, of fine to coarse white and tan reefy Cierbo sand yielding *Ostrea cierboensis*, *O. ligminuta*, and *Astrodapsis cierboensis* var. *branchensis* essentially throughout, *A. pabloensis* just above the middle, and twenty-one new species and varieties of *Astrodapsis* whose short ranges divide the upper half of the Cierbo into precise horizons averaging approximately 50 feet in thickness. *Ostrea titan* var. *prior*, an ancestral form much smaller than the typical variety, occurs at intervals through the upper half of the Cierbo. *Lyropecten*, *Trophon*, *et cetera*, are locally common.

An unconformity is present between the Cierbo and the overlying Neroly, as in most strandward areas in California. It is well exposed near the head of Discovery Gulch on the east side of Branch Canyon, where soft, rusty gray Neroly sand containing characteristic astrodapses can be seen to truncate hard, white Cierbo reefs containing different and equally characteristic forms. About 25 feet of the underlying reefs (Fig. 14) are here cut out in approximately 300 feet along their strike, this abnormally rapid cut-out indicating the site of a shallow post-Cierbo and pre-Neroly valley. Northwesterly, across the adjacent Bitter Creek, the Neroly rests on progressively lower horizons of the Cierbo. Zone 8-U and most of the zone 8-M of the upper Cierbo, a total of about 100 feet of strata, are cut out in approxi-

mately one mile.[44] Of fourteen species and varieties of *Astrodapsis* here present in the upper Cierbo, and thirteen species in the lower Neroly, not one has been observed to cross the unconformity. Lest readers unfamiliar with the extremely rapid evolution and short range of species of *Astrodapsis* conclude that this necessitates a long interval, the writers call attention to the fact that no collected species or variety of *Astrodapsis* is common to zones 7-U and 8-M of the middle and upper Cierbo respectively, though these zones are separated by but 87 feet of well exposed strata which appear to be conformable (Fig. 12). Only three species of this genus have been observed to range through as much as 600 feet of section in the district, and no species above the middle Cierbo to range through more than 125 feet. From these data it is inferred that the local unconformity between the Cierbo and the Neroly can conceivably (though improbably) represent as little as 125 feet of deposition or about one-sixth of a substage as the latter term is used herein, and on the basis of the evolutionary change between the two that it is probably equivalent to approximately 400 feet of deposition or about half of a substage.

Above the unconformity is 100–150 feet, according to the locality, of white and gray, fine to coarse, reefy lower Neroly sand yielding *Ostrea titan* s.s., *Astrodapsis cuyamanus*, *A. whitneyi*, *A. grandis*, *A. margaritanus*, *A. major* var. *parens*, *A. tumidus*, *A. californicus*, *A. coalingaensis*, and five new species of *Astrodapsis*. *Lyropecten*, *Trophon*, and other forms are locally common, with local *Turritella carisaensis* s.s.

Next above, conformably, is approximately 500 feet of middle Neroly siliceous shale with interbedded silts and fine sand containing *Ostrea titan* s.s., *Turritella carisaensis* s.s., *Lyropecten*, *Cyathodonta*, and other mollusks. This is best exposed between Branch and Newsome canyons.

Conformably overlying the shale member is about 400 feet of upper Neroly fine to medium sand. The lower half is white, marine, and yields *Ostrea titan* s.s., *Turritella carisaensis* s.s., and *Lyropecten*. This grades up to pink and brownish red non-marine sand and silty sand. The upper Neroly is best observed in Newsome Canyon; only its base is exposed in and west of Branch Canyon. It is too fine-grained in these areas to yield *Astrodapsis*, but in West Miranda Canyon of west Cuyama Valley its base yields *A. schencki* var. *mirandaensis*.

[44] At the time the preliminary paper by the senior writer (*op. cit.*) was written the unconformity had not been located, and only a part of the faunas had been classified. As a result, thicknesses then given for the Briones and Cierbo were too small, and that for the lower Neroly too large.

Thrust faulting on a large scale is present in the general area, which has been highly compressed and transversely shortened (Fig. 13). Eastward from Branch Canyon almost the entire Monterey is progressively and rapidly overridden by a thrust sheet of Temblor strata which reaches its maximum in Newsome Canyon where erosion has isolated a lobe of overriding Temblor that is now almost or quite surrounded by vertical beds of once overridden but now emergent Monterey. This thrust is southeast of, and does not override, the succession particularly described. A smaller thrust farther north which rides in the opposite (mountainward) direction cuts the part of the *Astrodapsis* succession which lies east of Branch Canyon, causes Cierbo there to override Neroly, and duplicates 540 feet of section near the mouth of Discovery Gulch, its point of maximum visible throw. From here this thrust strikes first southeasterly and then southerly along the east side of Discovery Gulch to the head of this gulch, then curves more easterly across Critical Gulch, after which it strikes southeast just within the northeast margin of a high potrero. *Astrodapsis* sequences composed of successive faunas occurring in the same specific and precise order both below and above the thrust allow the stratigraphic equivalency of horizons below and above to be ascertained within about 10 feet in the better exposed areas, and, in collaboration with marker beds, an occasionally closer correlation. The thrust is therefore little or no complication to a detailed faunal section that has been completed. Collectors are cautioned, however, that if it is crossed unawarely at any point Neroly faunas will be labelled Cierbo, or Cierbo faunas will be labelled Neroly.

West of Branch Canyon no certain evidence for a continuation of this thrust into the *Astrodapsis* succession of Bitter Creek has been observed. Except for local slumping, overturning, and one short and seemingly minor diagonal fault, the Bitter Creek section appears to be essentially uncomplicated from the top of the Temblor upward into the middle Neroly shale. The Cierbo-Neroly unconformity 100–150 feet below this shale is rarely well exposed, and is best located from the complete change in the echinoid fauna.

FAUNA OF THE MONTEREY

For many years one of the debated questions of California geology was: why is the Monterey sparse in megafossils, whereas the (supposedly) superjacent San Pablo and Santa Margarita abound in these? This problem arose from the early idea that Monterey time was one chiefly of shale, and that San Pablo and Santa Margarita times were those of chiefly sand deposition. Subsequent discovery that the type

San Pablo and Santa Margarita are merely coarse, strandward facies of the fine-grained basinward type Monterey disposed of the problem. Actually, Monterey time saw deposits of coarse material and a contained bulk of megafossils comparable with those of other times. That the idea which associates a particular time with a supposedly universal texture still persists is shown by the fact that fine-grained facies of Temblor age are still occasionally referred to as "Monterey shale," and coarse-grained facies of Monterey age are referred to as "Temblor sand," although the types of these two stages represent wholly successive times, neither exposes any strata represented in the other, and over much of California the two horizons are separated by unconformity.[45]

In the district discussed all of the more common facies of the Monterey are represented. The lower Monterey grades from basinward diatomaceous and siliceous shale facies to strandward reefy white and tan sand facies. The middle and upper Monterey show a similar gradation at certain horizons, but during most of these later times so much material was furnished the local district that only the coarser portions there came to rest, resulting in sandy deposits over the entire district, the finer materials being passed seaward to come to rest as shales and silts in other regions. The fine-grained basinward Monterey locally abounds in Foraminifera, but is barren of megafossils except a few small pelecypods capable of existing on mud bottoms. Coarse, strandward facies, on the contrary, furnish few Foraminifera but locally abound in megafossils.

The sheltered northwest head of the secondary trough furnished at times a peculiarly favorable environment for oysters, reefs several feet in thickness composed of close-packed, vertical shells of *Ostrea titan* s.s., and containing several million tons of calcium carbonate in this form, being widespread in the lower Neroly substage. *Lyropecten*,

[45] Judged from the inability of many geologists to visualize one texture grading laterally to another of very different aspect, perhaps the most valuable current service that universities can contribute to sedimentary geology is to impress upon students the importance of facies and their causes: the soul of sedimentation. Merely to inform students that lateral gradation occurs is not sufficient, because during life the geologist will read hundreds of papers referring to thousands of formations as "units," with the tacit implication that, though lateral variation occurs, equivalent formations are somewhat like separate red and black checkers on a board. That this shale or limestone sequence is correlative with that conglomeratic or sand sequence nearer the ancient strand is accepted, but the gradation of one to the other being rarely visualized, the two are conceived of as "units"—as contiguous red and black checkers. It is unfortunate that the word *facies*, which automatically suggests the relative, was not chosen as the physical term instead of the word *formation*, which expresses and perpetuates an early, erroneous belief that layers each of only one texture were laid down across a bowl from rim to rim. If a student is to be equipped adequately to attack problems of gradation he must be so trained that each time he reads or hears the word *formation* the word *facies* will occur to him, followed by the question: *wedge, or lens.*

Astrodapsis, *Trophon*, and *Cyathodonta* are present at intervals. The sheltered southeast head of the secondary trough had a similar Monterey environment and fauna which at times extended over much of the entire secondary trough.

Bitter Creek echinoid area.—Grant and Eaton have collected and studied the fauna of the Bitter Creek area of southern Cuyama Valley in considerable detail, and plan to publish a detailed description of the geology and species in the near future. Pending this time it seems advisable to include herein a synopsis of their findings to date, since the area is an integral part of the district being described. A full discussion is precluded at this time, for such would double the length of the present paper, the contribution being restricted to the following paleontological data and Plates II–IX. Brief remarks on certain conspicuous diagnostic characters of new forms are made in the explanation of plates. A more technical description of new species and varieties of invertebrates included in the present paper will be found in the separate faunal treatise by Grant and Eaton now in composition. Acknowledgment is made to the monographs of Clark[46] and of Kew,[47] whose wealth of information greatly facilitated the present study.

Stratigraphy, structure, faunal localities, substages, zones, and known faunal ranges are given in Figures 12 and 13. All localities are those of the University of California at Los Angeles, the depository. Except for collections illustrated in the excellent section given by Clark[48] for the Cierbo and Neroly at San Pablo Bay, and a fauna referred to specific lower sandstones in that region by Trask,[49] faunas reported from the Briones, Cierbo, and Neroly substages have usually come from isolated areas where unconformities below or above cause it to be uncertain what portions of substages are locally present. Published statements that an outlying collection is from the base or top of a substage are therefore not always reliable. For example, Briones or Neroly beds just above an unconformity at Mount Diablo may be well within successions bearing these names at San Pablo Bay, or *vice versa*. Also, though the type Santa Margarita of Salinas Valley is of Neroly age, some collectors have called all upper Miocene sands in coastal regions by this term, thus possibly misranging Cierbo or even Briones guide species up into the Neroly. For these reasons, except

[46] B. L. Clark, "Fauna of the San Pablo Group of Middle California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 8, No. 22 (1915), pp. 385–572.

[47] W. S. W. Kew, "Cretaceous and Cenozoic Echinoidea of the Pacific Coast of North America," *ibid.*, Vol. 12, No. 2 (1920), pp. 23–236.

[48] B. L. Clark, *op. cit.*, pp. 397–99.

[49] P. D. Trask, "The Briones Formation of Middle California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 13, No. 5 (1922), p. 140.

when published evidence is full and clear, the known range of an echinoid is given as evidenced in the extremely full Cuyama Valley sequence. Some of the known ranges will doubtless later be extended. However, in view of the short life of most species of *Astrodapsis*, together with the apparently nearly complete nature of the control section at Bitter Creek and the consecutive occurrence and abundance of its faunas, it is believed that most of the absolute ranges do not differ greatly from those charted.

Early, generalized varieties of *Astrodapsis* tended to have relatively long ranges, as may be seen by referring to Figure 12. Those having appreciable ranges are all comparatively simple, low-petaled forms. The relatively high-petaled early species *A. auguri* and *A. elevatum* are known from only one zone. Specialization upward, of which height of petals may be taken as one example, was accompanied by shorter ranges. At a culmination in upper Cierbo time such bizarre, highly specialized forms as *A. gregerseni*, *A. gregerseni* var. *fragilis*, and *A. johnsoni* were apparently each ranging through only about 10 or 20 feet of strata.

Relatively simple forms, few in number, are recorded from the Briones and the lower half of the Cierbo. About mid-Cierbo time a number of more specialized, short-ranged forms evolved. The upper Cierbo, as mentioned, saw extreme specialization and extremely short ranges. In the lower Neroly specialization was marked but was less extreme, and the average range had advanced slightly from the previous minimum. The strictly successive echinoid record is then lost.

As regards stocks, *Astrodapsis brewerianus* s.s. probably does not represent the first of its genus as was inferred by early workers from its barely raised petals. As stated on a previous page, poorly preserved specimens of *Astrodapsis* subpentagonal in outline, and thinner and higher-petaled than *A. brewerianus*, occur in basal Briones strata. These may be ancestral to *A. auguri*, which, found with *A. brewerianus* s.s., is a more advanced form than the latter. *A. brewerianus* is locally associated with four other Briones species, three of which, *A. auguri*, *A. galei*, and *A. schucherti*, are so different from it as to imply long-divergent paths of evolution.

Early stocks (Pl. V) persisted almost or quite without adulteration until the close of middle Cierbo time, and then all rapidly disappeared. Upper Cierbo astrodapses (Pls. VI and VII) are so radically different from those they displaced as to suggest that they represent immigrant stocks that came in closely spaced waves. The prevailingly large, graceful forms of the lower Neroly (Pls. VII–IX) are apparently of varied ancestry, the *A. cuyamanus* and *A. whitneyi* groups seeming to

stem from *A. pabloensis* (*A. brewerianus* stock), whereas *A. margaritanus* was clearly, and *A. major* var. *parens* probably, descended from the invading stock of *A. gregerseni*. No astrodapses have as yet been collected from the middle Neroly. The ornate *A. schencki* var. *mirandaensis* of the early upper Neroly is seemingly an outgrowth of the *A. whitneyi* group of the lower Neroly.

The faunal record of Cuyama Valley continues nearly to the extreme top of the local Miocene series which constitutes one of the most complete successions in the state. The Pliocene series, which follows the usual marked unconformity, is here entirely continental. Evolutionary change between the definite Miocene *Astrodapsis* sequence of Cuyama Valley and the oldest definite Pliocene *Astrodapsis* known elsewhere in California is rather profound, being indicated to be a much larger change than that which occurred during any lost record within the upper Miocene. In this connection *A. salinasensis*, which occurs near the contact between the two series in Salinas Valley and has been variously reported as from either the uppermost Miocene or the lower Pliocene, is so like *A. fernandoensis* of known lower Pliocene age and so unlike any known form from the upper Miocene of Cuyama Valley that occurrence above, rather than below, the contact between series is suggested as the more likely.

Although forms figured in the present paper more than double in number the known species and varieties of *Astrodapsis* in the upper Miocene of California, large gaps still exist in the record for this genus. Basal Briones species ancestral to described forms are at present known only from indeterminate specimens, the presumably long ancestry of advanced and highly specialized invading stocks of upper Cierbo time is completely unknown, the Cierbo-Neroly unconformity hides the evolutionary record between two entirely different assemblages, no species is certainly known as being from the middle Neroly, and only one or two from the upper Neroly. It thus seems almost certain, despite the incomparable Bitter Creek control section, that less than half of the species and only a small fraction of the varieties of *Astrodapsis* that lived along California coasts in upper Miocene time are at present known.

Oyster sequence.—The larger oysters in the upper Miocene of California (Pls. III and IV), which considered in their wide occurrence and abundance are perhaps the most useful guides to the upper Miocene, have commonly been lumped in the literature to such an extent that they have operated as hindrances rather than aids to correlation. For many years any large oyster found in the Miocene of California, from Vaqueros upward through Neroly time, was recorded as *Ostrea titan*,

whereas the typical variety of this species seems to be confined to the Neroly (late upper Miocene) substage. Similarly, any highly corrugated Neocene oyster was likely to be recorded as the Pliocene form *O. vespertina.*

A long step toward unravelling the tangle was taken by Clark in his fine monograph on the San Pablo group,[50] issued in 1915. Clark reexamined a number of previous collections, came to the conclusion that specimens labelled *Ostrea titan* from the pre-Neroly were *O. bourgeoisii,* and in effect restricted the known range of *O. titan* s.s. to the Neroly. The evidence of the nearly complete oyster succession of Cuyama Valley is in accord with this step. Clark listed *O. bourgeoisii* from the Briones and the Cierbo at San Pablo Bay. At Bitter Creek this species ranges through the Briones and the lower Cierbo; an occurrence unconformably just below the Neroly in the adjacent Newsome Canyon may be middle Cierbo. In the lower Briones *O. bourgeoisii* is associated with a relic *Turritella ocoyana* fauna.

Ostrea cierboensis, an ornate, broadly corrugated, more nearly round species than *O. bourgeoisii* but of about the same size and mass, appears in the upper Briones and ranges upward throughout the *Cierbo.* The grotesquely thick-shelled species *O. ligminuta* is known from the uppermost Briones and the lower and middle Cierbo. *O. titan* var. *prior,* apparently a direct ancestor of the subsequent *sensu stricto* variety but much smaller, has been collected through the upper half of the Cierbo. *O. titan* s.s. appears in the lower Neroly and ranges upward throughout this substage. *O. eucorrugata* occurs in the late lower Neroly of West Miranda Canyon and the La Rinconada Rancho of western Cuyama Valley; this distinct species, apparently a gigantic descendant of the ornate, large-cavitied, thin-shelled older *O. cierboensis,* has no specific relation to *O. titan* as was once inferred.

Correlation with the upper Miocene of San Pablo Bay.—The San Pablo Bay area, which includes the type localities of the Briones, Cierbo, and Neroly substages, is the most northerly of the important marine Miocene districts of California. Most type and control sections in the state commonly used as standards for molluscan and foraminiferal comparison are several hundred miles south. More or less progressively cooler waters for the state as a whole through the Miocene and Pliocene epochs cause each younger fauna to reflect, in part, a cooler environment; therefore, relatively cool northern Miocene environments in California tend to have faunas younger in aspect than those of contemporaneous southern faunas. If a northern district is just beyond the northern limit of prominant forms relied on in the south, the pseudo-younger aspect may be marked. If such ecologic

[50] B. L. Clark, *op. cit.,* pp. 447–48.

factors are unevaluated and ignored, homotaxial instead of time horizons will be correlated.

The San Pablo Bay area was apparently north of the preferred habitat of certain valued marker forms during parts of the Miocene. Tropical and subtropical clans of *Turritella* which head the Vaqueros and Temblor faunas are so far almost or quite unreported from the San Pablo Bay region. *Lyropecten*, there locally known from two or three species in the upper Miocene, was seemingly rare or absent for entire stages.

Fortunately, the fact that the Bitter Creek section yields all Briones, all Cierbo, and with two or three exceptions all Neroly species of *Astrodapsis* known from San Pablo Bay shows that this shallow-water genus was relatively little affected by moderate differences in temperature which could not be bridged by various mollusks and foraminifers. Owing to the remarkably short range of its species, precluding adaption of these with time, any two areas to which several of these are common can be correlated with a minimum of error.

That the Briones, Cierbo, and lower Neroly as determined at Bitter Creek correspond closely with these substages as established at San Pablo Bay is indicated by the fact that the recorded species of *Astrodapsis* from San Pablo Bay occur at Bitter Creek at the same positions and in the same sequence. In this connection the middle and upper Neroly as mapped in Cuyama Valley are seemingly in large part stratigraphically higher than the more *fossiliferous* portion of the type, but in view of the feature that Clark[51] included in the Neroly at least 574 feet of beds above the highest *Astrodapsis* he listed, since discontinuity within has nowhere been proved, and since the most useful single marker, *Ostrea titan*, ranges nearly or quite throughout, the writers consider that they have at present no adequate basis for differentiating a post-Neroly substage in the Miocene.

Correlation of Bitter Creek with the Morales syncline.—If the all-strandward Bitter Creek Monterey could be precisely correlated with the Monterey of the Morales syncline upper parts of which are composed of strandward and lower parts of basinward deposits, a dependable tie-in between the echinoderm and foraminiferal records would be established. Almost identical physical sequences for the Cierbo and Neroly successions in both areas, combined with the feature that two important oyster species which are separated by unconformity are present in both areas, leaves little doubt regarding the correlation of these substages. However, at Bitter Creek the lower part of the Monterey is fairly coarse Briones; in the Morales syncline it is the fine to medium *Valvulineria californica* zone. The impression conveyed by the

[51] B. L. Clark, *op. cit.*, p. 399.

parallel general sequences in the two areas plus the apparently conformable gradation upward of the lower parts into overlying middle parts, is that the Briones and the *V. californica* zone are approximate equivalents. This impression, however, is not proof.

The fact that in the Morales syncline *Ostrea bourgeoisii* has been collected in quantity 300 feet conformably above *Valvulineria californica* silt and sand furnishes the following alternatives: (1) if the local occurrence of this oyster is at a horizon of the Cierbo, as its range into this substage makes possible, then the *V. californica* zone is almost certainly Briones in age; or (2) if its local occurrence is Briones, as is also possible from its range, then presumably only an upper part of the *V. californica* zone is Briones; or (3) if this latter relation should both exist and coincide with a rather improbable equivalency of 800 feet of sandy Briones at Bitter Creek to 300 feet of sand at the Morales syncline, then none of the *V. californica* zone needs be Briones.

Kleinpell[52] has inferred that the *Valvulineria californica* zone is older than the Briones substage, apparently on the basis of a foraminiferal fauna from the Tice shale whose ecologic relations are undetermined, and a misconception regarding the age of the species herein described as *Astrodapsis hootsi* which caused him to classify this species two substages too low. Barbat and Johnson,[53] on the other hand, report a Briones megafauna to be closely related to the *V. californica* zone in Salinas Valley. From the facts that at Whiterock Bluff *V. californica* shale grades conformably into overlying sand yielding *Ostrea bourgeoisii*, that at Bitter Creek definite lower Briones includes a relic *Turritella ocoyana* fauna, and that the distinctive dwarf species *Astrodapsis hootsi* which occurs in the base of the *Baggina californica* zone (just above the horizon of *V. californica*) in the Santa Monica Mountains has been collected only from the early lower Cierbo at Bitter Creek, the present writers consider the *V. californica* zone to be either Briones in age or nearer this substage than has previously been supposed from homotaxial correlations between ecologically different southern and northern districts.

Correlation of Bitter Creek with the Santa Monica Mountains.—In the eastern Santa Monica Mountains of Southern California the *Valvulineria californica* zone of the Monterey is absent and the next younger foraminiferal zone, that of *Baggina californica*, overlaps with strong angular unconformity upon the upper Temblor. One species of

[52] R. M. Kleinpell, *op. cit.*, Fig. 14 and p. 47.

[53] W. F. Barbat and F. L. Johnson, "Stratigraphy and Foraminifera of the Reef Ridge Shale, Upper Miocene, California," *Jour. Paleontology*, Vol. 8, No. 1 (March, 1934), p. 7.

Astrodapsis, the peculiar dwarf *A. hootsi*, is locally common in the base of the *Baggina californica* zone at and near U. S. Geol. Survey loc. 30 (*Prof. Paper 165-C*) = U.C.L.A. loc. 1920, east of Mohn Springs. At Bitter Creek the apparently short-ranged *A. hootsi* has been collected in, and only in, definite early lower Cierbo. Less diagnostic, but corroborative, is the feature that *Plagioctenium raymondi*, which according to Woodring[54] is the most abundant fossil in the *Baggina californica* zone of the Santa Monica Mountains, is known only from the Cierbo and uppermost Briones of Bitter Creek. *A. hootsi* rather precisely correlates the base of the *Baggina californica* zone with the early lower Cierbo, and suggests that the 800 feet of Briones at Bitter Creek represents the *Valvulineria californica* zone which is absent in the eastern Santa Monica Mountains. It indicates that Kleinpell's[55] correlation of the Tice shale of San Pablo Bay with the *Baggina californica* zone of the Santa Monica Mountains is a homotaxial one departing at this bay 1,800 feet or more from time equivalency.

For many years nearly all authors assumed that the coarse, typical San Pablo group was stratigraphically above the fine, typical Monterey, an error that has perhaps caused more stratigraphic confusion in California than has any other. The typical San Pablo has now for some time been known to be a coarse, strandward facies of the fine, basinward, typical Monterey instead of being a stage above the latter. This revision, in turn, implies that about 4,000 feet of pre-Briones strata at San Pablo Bay from the Rodeo shale down to the Sobrante sandstone inclusive, which occupy the stratigraphic position of the transitional Temblor-Monterey and the Temblor elsewhere in the state, are of the latter ages; in other words, that an absence in this northerly region of most of the subtropical species relied on to the south has in the past caused these underlying strata also to be correlated about one stage too high. Due to this latter circumstance the San Pablo Bay district has previously appeared to have the peculiar, unlikely combination of exhibiting an extra 4,000 feet of upper Miocene, and lacking 4,000 feet of middle Miocene, compared with other parts of the state. If the known and implied ecological qualifications in this northerly region are recognized this anomaly disappears, and the San Pablo Bay region is seen to have probably much the same stratigraphic column as is present in other parts of California.

Ecology.—Ecologic features which cause megafaunas of Caliente Range and environs to have an older aspect in warmer, strandward

[54] W. P. Woodring, *in* H. W. Hoots, "Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California," *U. S. Geol. Survey Prof. Paper 165-C* (1931), p. 110.

[55] R. M. Kleinpell, *op. cit.*, Fig. 14.

areas than that of contemporaneous faunas in cooler, basinward areas have previously been mentioned for the Monterey and earlier stages of the Miocene.

Preliminary foraminiferal sampling indicates that the Miocene Foraminifera were affected by ecologic factors to much the same degree as was the megafauna; in the later Miocene, basinward horizons that yield normal foraminiferal assemblages appear to be represented in stratigraphically equivalent but warmer strandward areas by assemblages whose aspect is that of horizons from one to three zones older.

Various authors have discussed ecologic relations of the larger marine invertebrates of California in terms of latitude. Most of these have evaluated factors from relations between Recent faunas along the line of the present relatively straight coast, with the implied assumption that temperatures at certain depths of water during the Tertiary varied more or less directly according to the latitude. However, during the Tertiary the California seas were largely embayments (Fig. 1), in which, due to variously relatively sheltered and relatively open positions, local temperatures seem to have varied along lines of latitude as well as across these, with resulting local reversals of regional trends. From data set forth in the present paper it is apparent that during upper Vaqueros and lower Monterey times, at least, certain protected waters of Middle California locally supported faunas warmer and older in aspect than those of contemporaneous but more open waters in Southern California, an anomaly as regards latitude that presumably occurred here and there in the network of embayments throughout the Tertiary.

Advance in knowledge of ecologic factors and their application has not kept pace with the recent rapid advance in petroleum geology because faunal correlations from well to well have involved recognizing a vertical sequence of local ecologic horizons by their assemblages rather than by faunal ranges which more nearly denote successive times, and because, when correlating widely separated areas, changes in facies which preclude sheet reservoir sands in California make a pseudoequivalency based on homotaxial features more or less as satisfactory as one based on time. In paleontological research, on the other hand, homotaxial correlations which may cause the time horizon of the typical upper Temblor to be determined as lower Monterey at San Pablo Bay, and the time horizon of the typical Briones at this bay to be determined as post or pre-Briones in parts of Southern California, are not satisfactory.

Kleinpell[56] has contributed the most comprehensive general discus-

[56] R. M. Kleinpell, *Miocene Stratigraphy of California* (Amer. Assoc. Petrol. Geol., 1938), pp. 11–19, 81–84.

sion to date of factors affecting the ecology of California Foraminifera, although due to the present paucity of demonstrated applications he necessarily proceeds as if his accompanying correlations represent time instead of homotaxial equivalents. He infers that "the distribution of Foraminifera is perhaps affected more by temperature than by depth."

Natland[57] has made a practical demonstration. He shows, in comparing some temperature and depth relations of Foraminifera, that " . . . dissimilar faunas may be contemporaneous and, conversely, the correlation of two widely separated outcrops based on the similarity of their foraminiferal assemblages alone is apt to be erroneous." He further states that, "It would seem that temperature has a far greater influence than depth on some foraminifera."

It will ordinarily be difficult to ascertain the amount in which two similar but geographically distant fossil faunas may differ in age, since nearly all available standards for comparison are also relative. As a partial corrective, in the upper Miocene of California the comparatively long-ranged mollusks and Foraminifera may be checked against comparatively short-ranged species of the peculiarly unstable genus *Astrodapsis*. That astrodapses were affected by ecologic factors as were all other forms of life is certain, and is illustrated by regional differences in the habitat of species and by textural and other preferences at Bitter Creek. On the other hand, with a correct determination no correlation based on a fossil in place can err due to ecology in larger amount than the range of that form for all regions. Subsequent to specialization of the genus *Astrodapsis* about the middle of Cierbo time, few, if any, *sensu stricto* forms of this genus seem to have been able to maintain their characteristics through more than roughly 150 feet of strata as computed from an average rate of accumulation. A number of these forms are known to have spread widely, during their short life span, along the upper Miocene strands of California. To find them in every section is unnecessary; at a dozen widely separated points should be sufficient. If such forms of *Astrodapsis* occur at a certain position with relation to a molluscan or foraminiferal sequence in a northern part of the state, and 750 feet higher or lower in a similar sequence in a southern part, there is reason to believe that the molluscan or foraminiferal correlation is a homotaxial one departing 600 or more feet from time equivalency due to ecologic factors.

PLIOCENE(?)

Resting unconformably on the Monterey in various parts of the district, usually with angular discordance ranging from 5° to 20°, are

[57] M. L. Natland, "The Temperature and Depth Distribution of Some Recent and Fossil Foraminifera in the Southern California Region," *Bull. Scripps Inst. Oceanography*, Vol. 3, No. 10 (1933), pp. 225–30.

steeply dipping white, gray, yellow, and pink impure silty and pebbly continental sands of unknown age. This series, which is almost as highly deformed as the Miocene, is distinct from gently dipping alluvial fans (the Cuyama formation) that overlie it with profound discordance, but in poor exposures is difficult to segregate from locally continental beds of somewhat similar but usually more reddish aspect in the uppermost Miocene.

Pliocene(?) of the Morales syncline.—On the east side of Morales Canyon pink sand in the upper Monterey containing white and gray reefs of *Ostrea titan* s.s. (Neroly substage) is overlain with pronounced unconformity by a basal continental gravel composed largely of angular boulders, cobbles, and pebbles of Miocene siliceous shale. Above this basal gravel is 1,000 or more feet of gray continental sand containing thin pebbly layers and occasional worn, redeposited shells of upper Miocene oysters.[58] The lower half is relatively fine-grained, poorly sorted, and contains lenses of angular siliceous shale pebbles. The upper half is coarser, and most of its pebbles are well rounded fragments of acid igneous rocks, chiefly granitic. The lower half evidently represents a time during which Monterey rocks uplifted around edges of the trough were being degraded, and the upper half one after these had been eroded or covered and most materials were once more those coming from the ancient San Emigdio Mountains.

Pliocene(?) southwest of the Whiterock fault.—A long, narrow strip of Pliocene(?) continental deposits lies immediately southwest of the Whiterock thrust fault, being overridden by Miocene from the northeast side of this thrust. The same two divisions of continental deposits present in the Morales syncline are here exposed in much the same thickness, but the upper, here somewhat pinkish formation containing rounded granitic pebbles can be seen to rest unconformably on the lower, more poorly sorted one containing lenses of angular pebbles of siliceous shale.

Pliocene(?) of western Cuyama Valley.—At Devil's Elbow, beds in the top of the local Miocene section dipping 50° are overlain unconformably by continental gravel several feet thick composed almost entirely of pebbles of white siliceous shale which grades up to poorly bedded gray and yellow non-marine sand containing similar pebbles that dips about 35°.

Pliocene(?) of southwestern Cuyama Valley.—Steeply tilted non-marine Pliocene(?) crops out as small isolated exposures surrounded

[58] This is not the Cuyama formation of English, which is largely a gently dipping alluvial fan deposit of late Pleistocene age, but is an upper part of his type Morales: "... shale pebbles ... a few large oyster shells that are secondary ..." (*op. cit.*, p. 203).

and capped by alluvial fans at intervals almost throughout the length of southwestern Cuyama Valley. Due to prevailingly poor exposures this has been separated only approximately on Figure 3 from the underlying Miocene and the overlying late Pleistocene fans. East of Bitter Creek, where continental facies appear in the uppermost Miocene and progressively invade lower levels, it becomes increasingly difficult to segregate the two series, both of which dip nearly the same amount.

Pliocene(?) of the Wells Ranch syncline.—In the Wells Ranch syncline, where most of the upper Miocene as well as the Pliocene(?) is non-marine, both dip rather uniformly 50°–80°, and no undoubted discontinuity has as yet been located, the contact between these two series is indefinite. The writers have tentatively drawn the contact at the top of the highest volcanic outcrop observed, which separates two thick and differing physical successions along a line between ashy white sand below and relatively homogeneous gray and pinkish sand above. Defined as the beds above this line, the Pliocene(?) locally comprises not less than 2,000 feet of rather poorly sorted continental sand, a thickness that decreases southeasterly along a steep homoclinal belt extending from Wells Ranch for several miles in this direction. At the northwestern end of this belt the lower 1,700 feet is prevailingly gray, and contains coarser, lighter, more resistant beds; southeasterly this portion thins, becomes more homogeneous, and acquires a pinkish cast. Above the thick lower member is about 300 feet of light, silty sand that locally weathers to rounded ridges.

The Pliocene(?) of the general district is apparently entirely non-marine. So far as is known no search for terrestrial vertebrate faunas has been made. The most likely locality for the latter is presumably the southwest flank of the Wells Ranch syncline between Wells Ranch and a point about 4 miles southeast. A thick, steeply dipping succession dissected by numerous canyons is almost completely exposed over much of this distance.

PLEISTOCENE

No indications of lower, middle, or early upper Pleistocene deposits have been observed in the district, which seemingly participated fully in the diastrophic revolution and profound degradation whose effects were state-wide during much of this epoch. Late Pleistocene time, a period of subsidence during which the sea re-occupied the trenched continental shelf and flooded adjacent edges of California to depths ranging up to 1,500 feet, is represented in the particular district by two groups of alluvial fans, and by local lake deposits contempo-

raneous with part of the older and more important of these two fan successions.

Older alluvial fans.—These, designated the Cuyama formation by English, were apparently deposited as a result of the late Pleistocene depression of California, which must have brought the floor of Cuyama Valley down to within a few hundred feet of sea-level with a resulting reduction in the gradient of Cuyama River to where this stream could no longer remove material as fast as it was delivered to the valley. Great fans spread northeastward across Cuyama Valley from the high, rugged Sierra Madre Range, these meeting shorter fans that spread southwestward from the lesser Caliente Range. This older alluvial fan succession was originally several hundred feet thick over much of the valley area southwest of Cuyama River. It is best observed from the top of Caliente Mountain, from which viewpoint two immense fans in the 20-mile stretch between Green and Santa Barbara canyons, once joined but now separated by the powerful erosive action of Newsome and Salisbury creeks, testify to its former magnitude. Near the mountains the component beds were laid down on a slope of several degrees, and had an initial dip of this amount, but dips locally ranging up to 5° or more suggest that the present attitude may be in part a result of some late folding.

East of Bitter Creek this older succession is composed chiefly of yellowish silty sand, shaded in places with pink where derived in part from red, continental beds of lower Vaqueros age. West of Bitter Creek, where the sediments were derived in large part from marine Monterey, the succession is chiefly fine to medium-grained gray silty sand. Where poorly exposed as gray soil on ridges it is likely to be mapped by the unwary as upper Miocene or Pliocene(?), but in rare exposures along creeks its poor sorting, pale, lenticular fresh-water clay stringers, and low dips readily identify it.

During a part of this phase the then sluggish Cuyama River was presumably dammed or choked west of Carrizo Canyon by landslides in its gorge, for several hundred feet of strata resembling lake deposits cover the lower course of Cottonwood Canyon and vicinity in western Cuyama Valley. These include three nearly horizontal members composed upward respectively of pinkish, gray, and dark, sandy clay. The mapping on Figure 3 indicates the maximum area covered by the lake; during most of its existence it had a smaller extent, with gray alluvial fans interfingering its edges and slowly encroaching on it as the assumed natural rock dam was gradually removed.

Younger alluvial fans.—Following the older alluvial fan succession after an interval of rather balanced conditions without trenching,

PLATES I–IX

EXPLANATION OF PLATE I

Miocene turritellas, natural size

FIG. 1.—*Turritella inezana* var. *hoffmani* Gabb. Spec. 3926. University of California at Los Angeles loc. 548. The oldest known variety of the *T. inezana* clan. Occurs 20 feet above the base of the Vaqueros of Caliente scarp. Similar to *T. inezana* s. s. except that it has essentially flat-sided whorls instead of the characteristic concave whorls of the typical form, the subsutural spiral cord is very low and indistinct instead of being the most pronounced, and the entire specimen is more robust and has a larger apical angle. Known range: early lower Vaqueros.

FIG. 2.—*Turritella inezana* var. *bicarina* Loel and Corey. U.C.L.A. spec. 1704. Simi Valley. Known range: late lower Vaqueros.

FIG. 2a.—*Turritella inezana* var. *bicarina* Loel and Corey. Calif. Inst. Tech. spec. 1086. C.I.T. loc. 572. Upper Sespe Creek.

FIG. 3.—*Turritella inezana* var. *sespeensis* Arnold. U.C.L.A. spec. 3925. Piru Creek. Donated by W.S.W. Kew. Known range: late lower and early upper Vaqueros.

FIG. 3a.—*Turritella inezana* var. *sespeensis* Arnold. U.C.L.A. spec. 2305. A flattened but well preserved specimen from the Vedder sand of the Poso oil field. Donated by Wayne Loel.

FIG. 4.—*Turritella inezana* var. *santana* Loel and Corey. Paratype. U.C.L.A. spec. 2302. Univ. Calif. loc. 6128, Santa Ana Mts. Known range: early upper Vaqueros.

FIG. 5.—*Turritella inezana* Conrad. Spec. 8840. U.C.L.A. loc. 574 (mid-upper Vaqueros). Known range: upper Vaqueros.

FIG. 5a.—*Turritella inezana* Conrad. Spec. 8844, U.C.L.A. loc. 485 (late upper Vaqueros).

FIG. 6, 6a.—*Turritella inezana* var. *altacorona* Loel and Corey. Specs. 8846 and 8847. U.C.L.A. loc. 535. Known range: late upper Vaqueros.

FIG. 7.—*Turritella ocoyana* Conrad. Spec. 8850. U.C.L.A. loc. 540 (early upper Vaqueros). Known range: upper Vaqueros, Temblor, transitional Temblor-Monterey, and lower Briones.

FIG. 7a.—*Turritella ocoyana* Conrad. Spec. 8851. U.C.L.A. loc. 564 (late middle Temblor).

FIG. 7b.—*Turritella ocoyana* Conrad. Spec. 8852. U.C.L.A. loc. 474 (late middle Temblor).

FIG. 8.—*Turritella ocoyana* var. *bösei* Hertlein and Jordan. Spec. 8855. U.C.L.A. loc. 537 (late upper Vaqueros). Known range: upper Vaqueros, Temblor, transitional Temblor-Monterey, and lower Briones.

FIG. 8a.—*Turritella ocoyana* var. *bösei* Hertlein and Jordan. Spec. 8856. U.C.L.A. loc. 535 (Vaqueros-Temblor transition).

FIG. 8b.—*Turritella ocoyana* var. *bösei* Hertlein and Jordan. Spec. 8857. U.C.L.A. loc. 565 (mid-middle Temblor). A specimen intermediate between this variety and *T. ocoyana* s. s.

FIG. 9, 9a.—*Turritella carisaensis* var. *padronesensis* Grant and Eaton, n. var. Spec. 7352-A, holotype. Spec. 7352-B, paratype. U.C.L.A. loc. 472. This variety seemingly occurs much lower in the column than does the typical *T. carisaensis*. It differs from the latter chiefly in having a rounded subsutural spiral cord instead of an angular or subangular keel some distance below the suture. Furthermore, the suture of *padronesensis* is appressed, and the whorl is concave below the spiral cord. *T. inezana* var. *altacorona*, though probably related, possesses a secondary cord below the pronounced upper cord, between which one or more fine spiral threads may be apparent. Known range: lower 500 feet of white and reddish beds immediately above the Temblor, northeast flank of Caliente Range.

FIGS. 10, 10a.—*Turritella carisaensis* Anderson and Martin. Specs. 8961, 8962. U.C.L.A. loc. 1832 (early upper Neroly). This species has occasionally been confused with *T. inezana* var. *altacorona*, a probable ancestor, although the two forms are distinct and have ranges that are almost two full stages apart. *T. carisaensis* differs from *T. inezana* var. *altacorona* in having an angular keel some distance below the suture, and whorls which are parallel-sided below the keel, the apical diminution being attained by the considerable slope of the whorls above the keel toward the suture. Known range: throughout the Neroly substage; lower, middle, and upper.

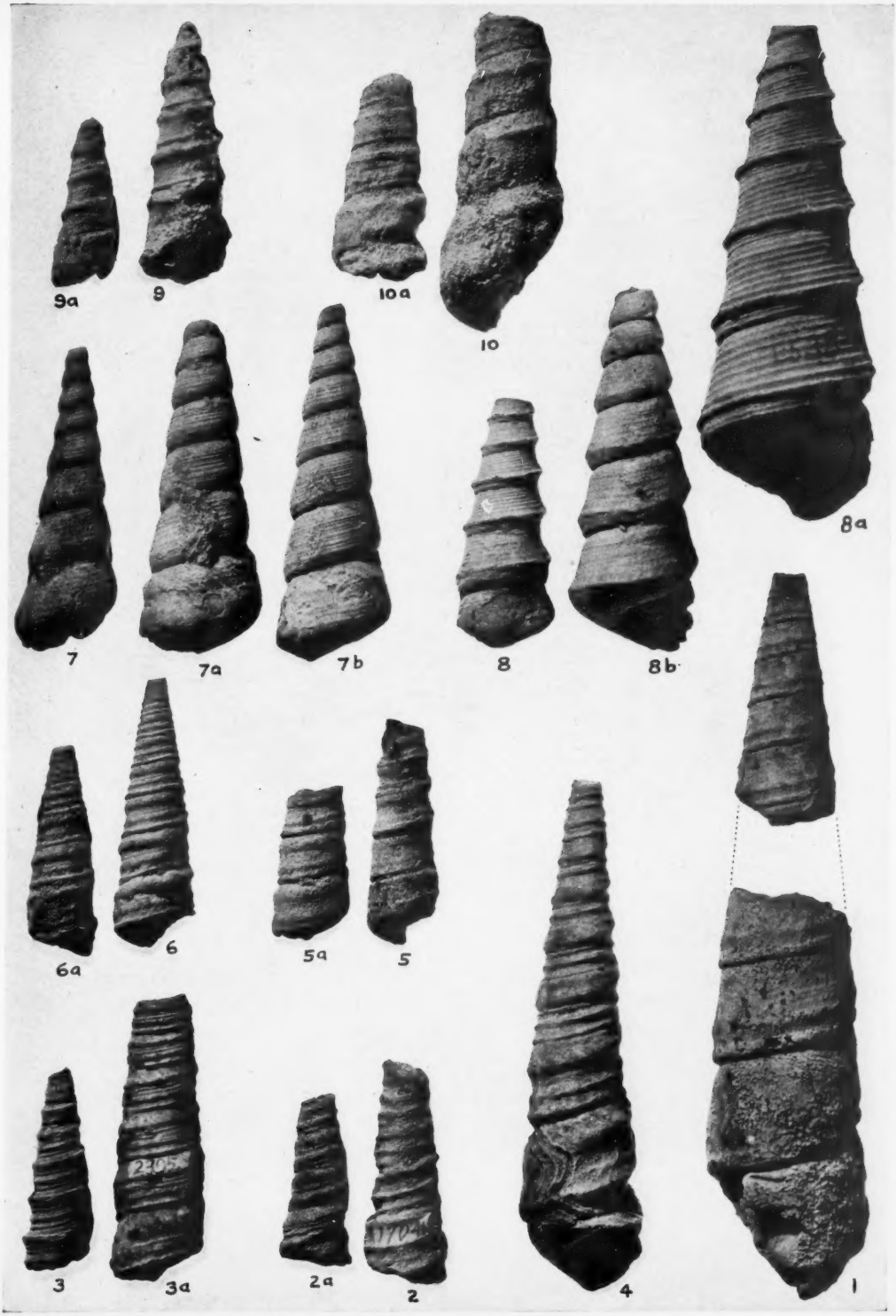

PLATE I

EXPLANATION OF PLATE II

Figures natural size

FIG. 1.—*Echinarachnius norrisi* (Pack). Spec. 8865. U.C.L.A. loc. 492 (early upper Vaqueros). Known range: upper Vaqueros and Temblor.

FIG. 2.—*Ostrea altatemblorensis* Grant and Eaton, n. sp. Holotype. Spec. 8970. U.C.L.A. loc. 512. Lower (left) valve. Average length about 6 inches; width commonly from a third to a half of this. Lower valve moderately thick, with 5–8 characteristically narrow, somewhat angular, rather evenly spaced, in many specimens almost knife-edge, radial ribs separated by rounded trough-like interspaces which may bear minor riblets. Upper (right) valve thinner, flattish, with irregular, concentric growth rugosities, but without definite continuous radial sculpture. Ligamental pit of lower valve concave, elongate, tapering, and ordinarily curved. Differs from *O. wiedeyi* of the older Miocene in its fewer, narrower plications, and the wide, rounded troughs between these. Differs from the Pliocene species *O. vespertina* in all of the foregoing attributes, and in its more elongate shape, larger size, and thicker valves. Known range: upper Temblor.

FIG. 3.—*Echinarachnius kewi* Grant and Eaton, n. sp. Paratype. Spec. 8701. U.C.L.A. loc. 1709. Abundant in hard reefs of the lower Briones of Bitter Creek, where it is too brittle to recover whole. The fragment figured shows parts of the apical system. Fragmental specimens attain a diameter of 4 or more inches. A very large, deeply notched, lobate species related to the older form *E. norrisi* from which it is presumably descended. Differs from *E. norrisi* in its markedly larger size, and in having a less angulate ambitus, which, however, is lobate. Known range: lower Briones (earliest upper Miocene) of Bitter Creek, just above Temblor-Monterey unconformity. Named in honor of W.S.W. Kew.

FIG. 4.—*Boreotrophon stuarti* var. *cierboensis* Grant and Eaton, n. var. Holotype. Spec. 8935. U.C.L.A. loc. 1856. Shell similar to typical *B. stuarti* but with much less prominantly lamellar axial ribs, and stronger, more numerous, closely spaced, rounded spiral cords. Whorls coronated by projections from axial ribs close to upper suture. Known range: early upper Cierbo.

FIG. 5.—*Nucella rankini* Grant and Eaton, n. sp. Holotype. Spec. 8936. U.C.L.A. loc. 1644. Shell of moderate size, consisting of four or five post-nuclear whorls including the body whorl; spire elevated, regularly enlarging; sculpture consisting of about ten angular, in some specimens somewhat lamellar, axial ribs, and numerous round, closely spaced revolving cords which continue over the axials except on upper third of each whorl where they become weak or obsolete; aperture subquadrate; anterior canal moderately long, stout, with a strong siphonal fasciole. Known range: mid-upper Cierbo. Named in honor of Wilbur D. Rankin.

FIG. 6.—*Trophon gillulyi* Grant and Eaton, n. sp. Holotype. Spec. 8937. U.C.L.A. loc. 1849. Shell of moderate size, rather high-spired, consisting of four or five post-nuclear whorls sculptured with about fourteen prominant lamellar axial ribs per whorl, the lamellae produced and somewhat guttered at the margin of a narrow subsutural tabulation; spiral sculpture absent; aperture ovately subquadrate; anterior canal produced, recurved, with a moderately prominent siphonal fasciole. Known range: mid-upper Cierbo. Named in honor of James Gilluly.

FIG. 7.—*Trophon clarki* var. *cuyamanus* Grant and Eaton, n. var. Holotype. Spec. 8938. U.C.L.A. loc. 1725. The form originally described as *T. gracilis* var. *pabloensis* Clark from the Cierbo was renamed *T. gracilis* var. *clarki* by Trask, the former name being preoccupied. *T. clarki* is herein considered to be of full specific rank rather than a variety of the Recent species *T. gracilis* Perry. The new variety of *T. clarki* figured from the lower Neroly is somewhat similar to the Cierbo form, but is quite unlike the high-spired shell figured by Trask from the Briones. *T. clarki* var. *cuyamanus* differs from typical *T. clarki* chiefly in having a lower spire. Known range: lower Neroly.

FIG. 8.—*Trophon carisaensis* var. *mirandaensis* Grant and Eaton, n. var. Holotype. Spec. 8939. U.C.L.A. loc. 1777-A. Similar to typical *Trophon carisaensis* except that the spire is lower and the tabulation on the upper portion of the whorls is much less steeply inclined. This variety, from the highest marine Miocene of Cuyama Valley, presumably represents a late variation of the typical form. Known range: early upper Neroly.

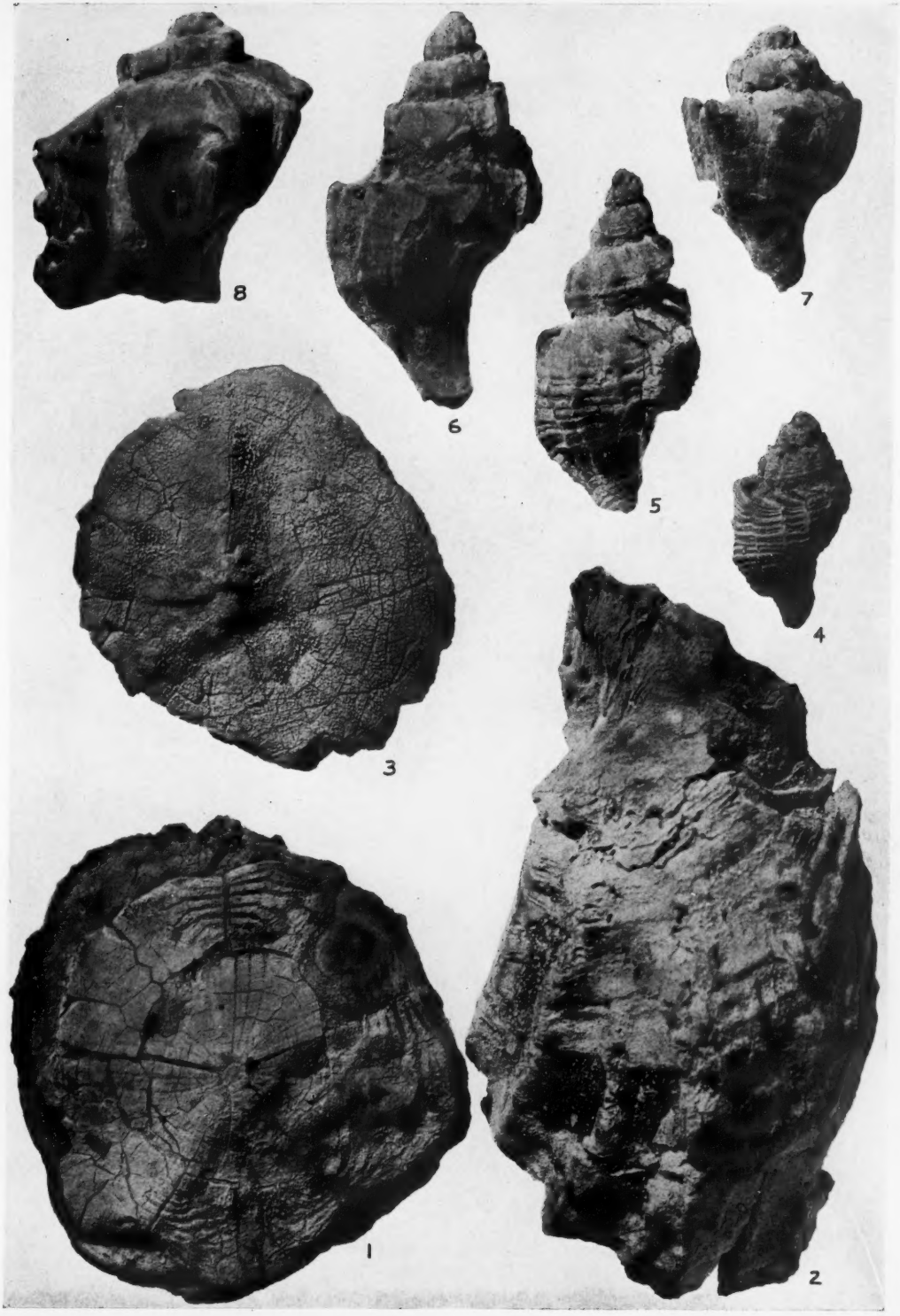

PLATE II

EXPLANATION OF PLATE III

Figures natural size

FIG. 1.—*Ostrea bourgeoisii* Remond. Spec. 8975. U.C.L.A. loc. 1820. Fragment of lower (left) valve, showing the characteristic narrow, commonly curved ligamental pit and uneven, wavy growth lamellae which differentiate this species from *O. titan* and *O. titan* var. *prior*. Average adult is about 7 inches long. No specimen observed has much more than half the length of an adult *O. titan;* has commonly the length but only about half the mass of *O. titan* var. *prior*. Differs from *O. ligminuta* of somewhat similar average length in its much thinner valves, relatively large body cavity, longitudinally curved shell, and uneven growth lamellae. From *O. cierboensis* in being highly elongate instead of sub-rounded in outline, in having a narrow, round, and elongate instead of a wide, flattish, and extremely short ligamental pit, and in lacking the broad, somewhat even radial plications of the latter. Known range: at Bitter Creek, throughout the Briones and lower Cierbo. (An occurrence in Newsome Canyon just below the Cierbo-Neroly unconformity appears to be middle or upper Cierbo.)

FIG. 2.—*Ostrea cierboensis* Grant and Eaton, n. sp. Holotype. Spec. 8980. U.C.L.A. loc. 1751. View showing lower (left) valve. Averages 5–6 inches in length and about 4 in width. Differs from all other known large upper Miocene oysters of California in being nearly as wide as long, and in having broad, somewhat regular radial plications on the lower valve. Upper (right) valve thin and flattish. Moderately thin-shelled, large-cavitied, with a broad, very short, flattish ligamental pit commonly about 1 inch wide and ½ inch long. Well preserved specimens normally occur as matched valves. Has probably previously been erroneously identified as the smaller and younger species *O. vespertina* (Pliocene). Differs from the latter species in its larger size, thicker shell, and fewer, broader plications. Known range: throughout the Cierbo substage, and upper Briones. Appears at Bitter Creek about 250 feet below the top of the Briones, and is found at intervals upward to the truncated top of the Cierbo.

PLATE III

EXPLANATION OF PLATE IV

Figures natural size

FIG. 1.—*Ostrea ligminuta* Grant and Eaton, n. sp. Holotype. Spec. 8985. U.C.L.A. loc. 1795. Oblique side view of lower (left) valve. This species, where previously found, has probably been classified as either an immature *O. titan* or an unusually thick-shelled *O. bourgeoisii*. Averages 6 or 7 inches in length; some specimens attain 9 inches. Ligamental pit, minute *in proportion* to the exceedingly thick equal valves, averages about $\frac{5}{8}$ inches in width, and ranges from 1 to 3 inches in length. *O. ligminuta* differs from *O. titan* in its relatively much narrower, in some individuals curved, ligamental pit, even more prodigiously thick valves, commonly thicker than wide, and normally smaller size. Also, the laminae or shell layers as seen in cross section are strongly curved instead of relatively straight, which gives it its extreme thickness in proportion to width. Then too, the beak is thick, massive, broadly rounded, and in most specimens protrudes beyond the ligamental pit. From *O. bourgeoisii* of somewhat similar over-all length and ligamental pit it differs in its extremely thick and massive valves, which are essentially straight instead of curved, its remarkably small body cavity, and relatively smooth growth lamellae. It has no resemblance whatever to the ornate, plicated, thin-shelled, large-cavitied *O. cierboensis* having a broad, short, flattish ligamental pit, but is the opposite in all of these attributes. The range of *O. ligminuta* overlaps that of *O. titan* var. *prior*, which latter form, less massive, has the broad, straight ligamental pit, relatively flat laminae, and other characteristics of *O. titan*. The average specimen, which is near the holotype in size and medial thickness, has a heavier, more protruding beak than is exhibited by the somewhat worn type. Known range: late upper Briones, and lower and middle Cierbo.

FIG. 2.—*Ostrea titan* var. *prior* Grant and Eaton, n. var. Paratype. Spec. 8991. U.C.L.A. loc. 1745. Fragment of upper (right) valve showing convex ligamental callous of *O. titan* character, and even, flattish growth lamellae at the margins. In nearly all observed respects except size *O. titan*. Presumably ancestral to that gigantic Neroly form. Averages 6 or 7 inches in length. Differs from *O. titan* in having little more than half the length, and thus only a fraction of the mass, of the latter. Since both typical *O. titan* and this ancestral variety are commonly found in quantity, the markedly smaller size is quite diagnostic. Where previously observed has presumably been classified as the young of *O. titan*. Known range: late middle and upper Cierbo.

FIG. 3.—*Ostrea titan* Conrad. Spec. 8995. U.C.L.A. loc. 1766. Fragment showing convex ligamental callous of upper (right) valve of the titanic, massive, small-cavitied, equi-valved oyster of the Neroly (late Upper Miocene). From this locality matched-valve specimens up to $17\frac{1}{2}$ inches in length and 9 inches in thickness have been collected. The average whole specimen with matched valves is about 1 foot long and 4 or 5 inches thick. Nearly all of the five large upper Miocene oysters differentiated in the present paper were originally lumped under the name *O. titan;* hence, the reported range of the form in the older literature is unreliable. *O. titan* differs so markedly from *O. bourgeoisii* and *O. cierboensis* that the figures of the three herein presented are sufficient without further remark. From the related *O. ligminuta* it differs in having a ligamental pit about twice as wide in proportion to mass, a total average length nearly twice as great, a less massive, less protruding beak, laminae or shell layers which seen in cross section are relatively flat instead of strongly curved, and valves commonly wider than thick instead of the reverse. It has no resemblance except outer size to the ornate, large-cavitied, fragile *O. eucorrugata*, which latter is apparently a gigantic descendant of *O. cierboensis*. From the ancestral *O. titan* var. *prior* it differs, so far as at present ascertained, only in having nearly twice the length and breadth with a corresponding mass. Known range: throughout the Neroly substage; lower, middle, and upper.

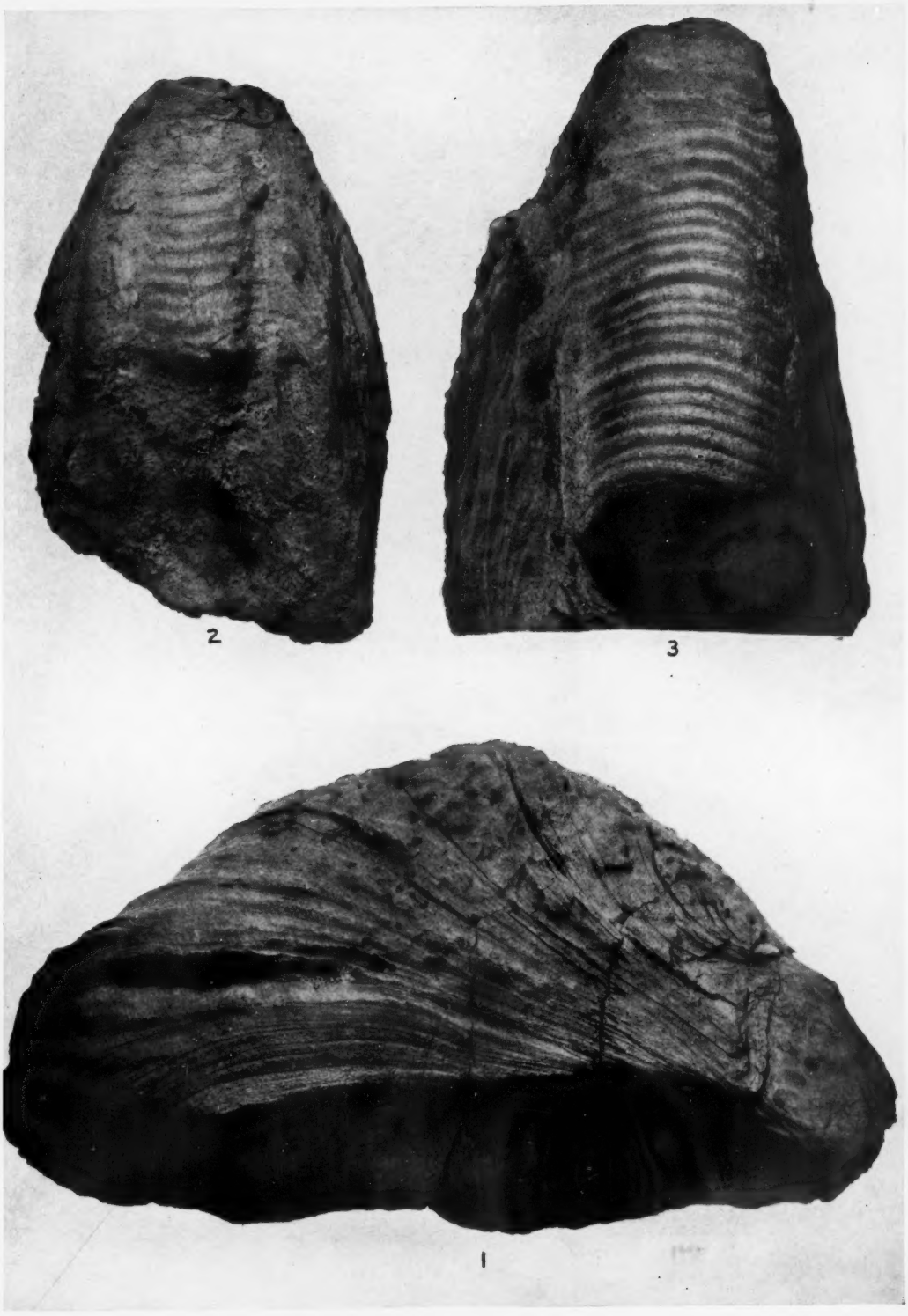

PLATE IV

EXPLANATION OF PLATE V

Briones, and lower and middle Cierbo astrodapses, natural size except for Fig. 12½, arranged in superposition

FIG. 1.—*Astrodapsis* sp. a. U.C.L.A. loc. 1833. Poorly preserved specimens having moderately notched ambitus, and raised petals flaring at margin of test. Test approximate size of *A. brewerianus* but thinner and more elongate. Lower Briones, associated with *A. brewerianus*.

FIG. 2.—*Astrodapsis brewerianus* Remond. U.C.L.A. locs. 1833 and 1869. (Indicating occurrences in lower Briones for superposition.) Occurs with sp. a.

FIG. 4.—*Astrodapsis auguri* Grant and Eaton, n. sp. Holotype. Spec. 8710. U.C.L.A. loc. 1333. Subpentagonal in outline, ambitus prominantly notched, high, peaked test, and moderately raised petals whose slope is essentially uniform from apex to margin. Known range: early upper Briones. Named in honor of the late Irving V. Augur.

FIG. 5.—*Astrodapsis brewerianus* Remond. Homoeotype. Spec. 8715. U.C.L.A. loc. 1333. Known range: throughout Briones substage.

FIG. 6.—*Astrodapsis schucherti* Grant and Eaton, n. sp. Holotype. Spec. 8720. U.C.L.A. loc. 1333. Apparently ancestral to *A. cierboensis* var. *branchensis* from which it may be distinguished by its more markedly raised and narrower petals. Known range: upper Briones. Named in honor of Charles Schuchert.

FIG. 7.—*Astrodapsis diabloensis* Kew. Homoeotype. Spec. 8725. U.C.L.A. loc. 1838. Known range: upper Briones.

FIG. 8.—*Astrodapsis galei* Grant and Eaton, n. sp. Holotype. Spec. 8730. U.C.L.A. loc. 1838. Distinguished from all other known astrodapses by the extreme narrowness of its petals, which otherwise resemble those of *A. diabloensis*. Ambitus thinner, and apex more peaked, than in the latter. Known range: upper Briones and lower and middle Cierbo. Named in honor of Hoyt S. Gale.

FIG. 9.—*Astrodapsis brewerianus* var. *bitterensis* Grant and Eaton, n. var. Holotype. Spec. 8735. U.C.L.A. loc. 1838. Test thinner, more notched, and petals more raised than in *A. brewerianus*. Known range: upper Briones; doubtfully lower and early middle Cierbo.

FIG. 10.—*Astrodapsis schucherti* var. *affinis* Grant and Eaton, n. var. Holotype. Spec. 8740. U.C.L.A. loc. 1838. Intermediate between *A. schucherti* below and *A. cierboensis* var. *branchensis* above. Differs from the former in its lower and broader, and from the latter in its higher, petals. Known range: late upper Briones.

FIG. 11.—*Astrodapsis brewerianus* var. *emergens* Grant and Eaton, n. var. Holotype. Spec. 8745. U.C.L.A. loc. 1798-A. Petals more raised than in *A. brewerianus*, and have a slightly delayed marginal flare; outline of test may be noticeably subpentagonal. Intermediate between *A. brewerianus* var. *bitterensis* and *A. ovalis*. Differs from the former in having a somewhat oval upper surface, thinner ambitus, and slightly delayed marginal flare of petals; from the latter in having distinctly raised petals, and a much lower, less ventricose, less discoidal dorsal surface. Known range: early lower Cierbo (misplotted on chart).

FIG. 11a.—*Astrodapsis hootsi* Grant and Eaton, n. sp. Holotype. Spec. 8399-A. U.C.L.A. loc. 1920 (Santa Monica Mts.). Petals commonly appreciably raised, as in the holotype, but in some paratypes are low. Differs from typical *A. brewerianus* in its dwarf size and normally much higher petals having a delayed marginal flare. From *A. brewerianus* var. *emergens*, its nearest and rather close relative, chiefly in its delayed instead of semi-delayed marginal flare of petals, and dwarf size. From all members of the *A. brewerianus* clan, to which it is related, in having a markedly delayed, stubby marginal flare of petals, only faint to imperceptible twin notches at the bivium, and dwarf size. Known range in the type region: base of *Baggina californica* zone. (The holotype is the only echinoid figured in the present paper from outside of Cuyama Valley.) Named in honor of Harold W. Hoots.

FIG. 11b.—*Astrodapsis hootsi* Grant and Eaton, n. sp. Homoeotype. Spec. 9200. U.C.L.A. loc. 1798-B (Bitter Creek). Collected approximately 10 feet stratigraphically above the related *A. brewerianus* var. *emergens*. Associated with early forms of *A. cierboensis* var. *branchensis*. Known range at Bitter Creek: early lower Cierbo.

FIGS. 12, 12a.—*Astrodapsis cierboensis* var. *branchensis* Grant and Eaton, n. var. Paratype (12), spec. 8755, U.C.L.A. loc. 1745; holotype (12a), spec. 8750, loc. 1854. The two forms shown occur together, and intergrade, throughout the range. Differs from typical *A. cierboensis* in having slightly narrower petals, less open at their ends, and a slightly higher test. Known range: Cierbo (except extreme top), and late upper Briones.

FIG. 12½.—*Astrodapsis elevatum* Grant and Eaton, n. sp. Holotype ×¾. Spec. 9205. U.C.L.A. loc. 1876. The earliest known *Astrodapsis* having highly raised petals. Intermediate in attributes between the primitive *A. brewerianus* (via species *a*) clan of the Briones, and the advanced *A. gregerseni* clan of the upper Cierbo. Presumably represents a connecting link which evolved, migrated elsewhere, and there developed into forms which returned during the great invasion of upper Cierbo time as *A. gregerseni* and related species. Differs from *A. diabloensis* in having highly raised, sloping petals, a fairly high central region, and an elongate, subpentagonal test. From *A. pabloensis* in having higher petals, an elongate test, and less prominent notches at the bivium. From the entire *A. gregerseni* clan in having petals which lose all elevation at the ambitus, and there have the wide marginal flare of the *A. brewerianus* clan. Known range: early lower Cierbo.

FIG. 13.—*Astrodapsis reedi* Grant and Eaton, n. sp. Holotype. Spec. 8765. U.C.L.A. loc. 1335. Small, markedly elongate test; narrow, rather high, distinct petals which commonly widen without constriction from center to margin; otherwise, close to *A. brewerianus* var. *bitterensis*. Known range: mid-middle Cierbo; doubtfully lower Cierbo. Named in honor of the late Ralph D. Reed.

FIG. 13a.—*Astrodapsis reedi* Grant and Eaton, n. sp. Paratype. Spec. 8769, U.C.L.A. loc. 1745. Worn specimen figured to show aspect after erosion has lowered petals and reduced notches.

FIG. 14.—*Astrodapsis armstrongi* Grant and Eaton, n. sp. Holotype. Spec. 8775. U.C.L.A. loc. 1770-B Ultra thin, flat test, the thinnest in known astrodapses; only slightly raised petals that widen gradually and uniformly in the proximal two-thirds of their length, then gradually flare widely to the ambitus. Known range: mid-middle Cierbo. Named in honor of Harold K. Armstrong.

FIG. 15.—*Astrodapsis altus* var. *antiquus* Grant and Eaton, n. var. Holotype. Spec. 8760. U.C.L.A. loc. 1745. This possibly ancestral variety differs from typical *A. altus* in having a wider, less elongate test, and slightly broader petals, more open at ends, which resemble those of *A. cierboensis* var. *branchensis* and which extend nearer the margin of the test. Known range: mid-middle Cierbo.

FIG. 16.—*Astrodapsis diabloensis* var. *superior* Grant and Eaton, n. var. Holotype. Spec. 8770. U.C.L.A. loc. 1745-A. Close to *A. diabloensis*, but differs in having a slightly elongate, slightly thinner test, a moderately and rather uniformly ventricose instead of a more or less flattish test— and more accentuated notches at the bivium (Many specimens are more extreme in these respects than is the holotype.) Known range: late middle Cierbo.

FIG. 17.—*Astrodapsis ovalis* Grant and Eaton, n. sp. Holotype. Spec. 8780. U.C.L.A. loc. 1841. High, smoothly oval upper surface rising from a thin ambitus. Close to the ancestral form *A. brewerianus* var. *emergens*, but differs in having a much higher, smoother, more ventricose, more discoidal dorsal surface. Known range: late middle Cierbo.

FIG. 18.—*Astrodapsis brewerianus* var. *junior* Grant and Eaton, n. var. Holotype. Spec. 8785. U.C.L.A loc. 1794. Nearly identical to the Briones form *A. brewerianus* except that it has an exceedingly thin test little more than half as thick. Medially ventricose variants approach a quasi *A. ovalis* aspect, showing that these two, whose horizons are but a few feet apart, are rather closely related. Known range: late middle Cierbo.

FIG. 19.—*Astrodapsis pabloensis* Kew. Spec. 8790. U.C.L.A. loc. 1727. Records a specialization of the *A. brewerianus* clan shortly before the local eclipse of the latter in upper Cierbo time. Known range: late middle Cierbo.

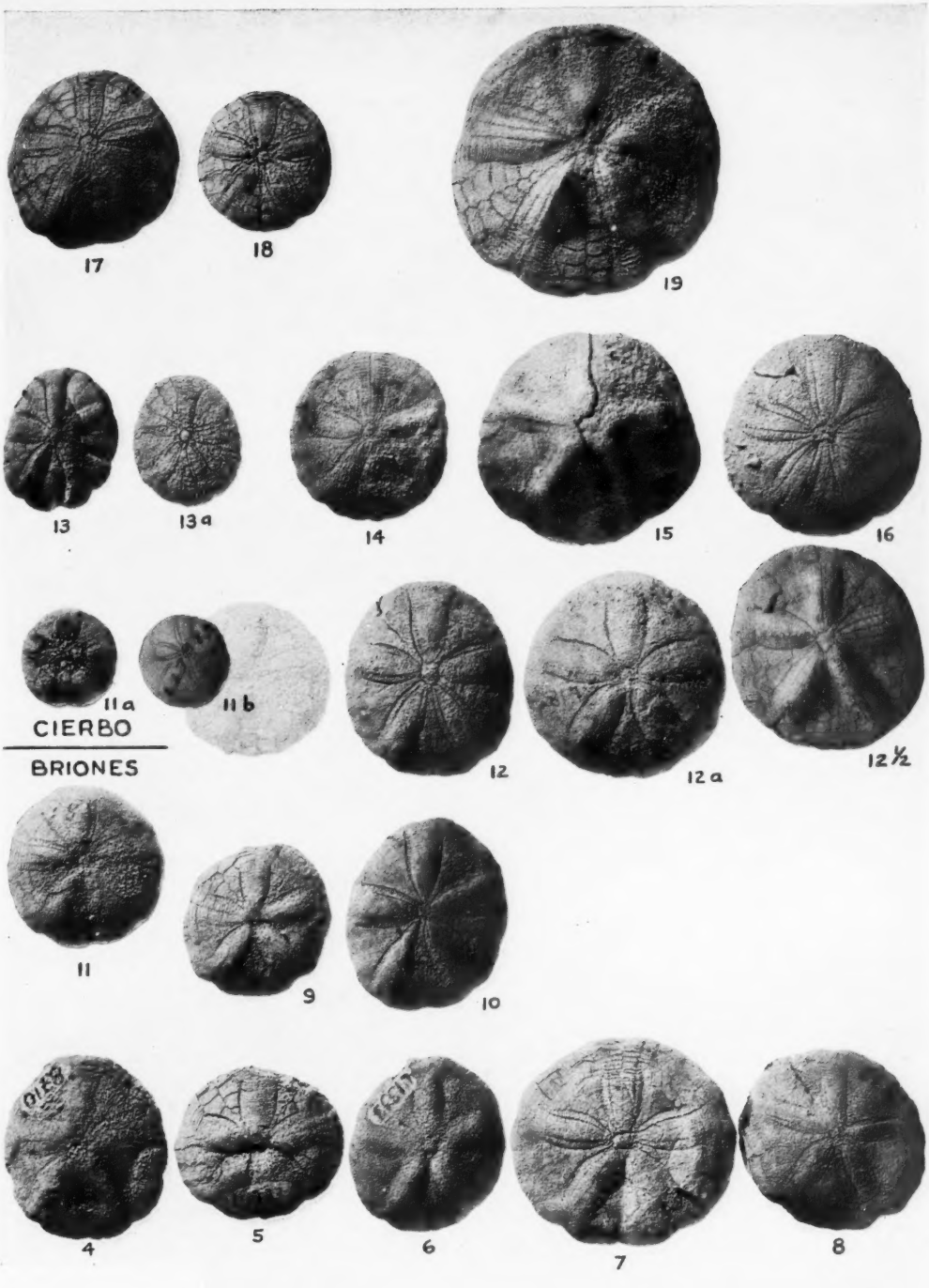
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PLATE V

EXPLANATION OF PLATE VI

Upper Cierbo astrodapses, natural size.
See footnote* for superposition

FIG. 1.—*Astrodapsis cutleri* Grant and Eaton, n. sp. Holotype. Spec. 8795. U.C.L.A. loc. 1848. Probably descended from *A. pabloensis*, from which it differs in having narrower petals that are less raised, and, particularly, in its bell-shape due to an accentuated ventricosity in the central portion of the dorsal surface which differentiates it from all other known pre-Neroly species. This species lived just before the great invasion of new, supplanting stocks into the Cuyama Valley district in mid-upper Cierbo time. Known range: early upper Cierbo. Named in honor of Willard W. Cutler, Jr.

FIG. 2.—*Astrodapsis gregerseni* var. *fragilis* Grant and Eaton, n. var. Holotype. Spec. 8800. U.C.L.A. loc. 1342. The immediate ancestry of this distinct species and clan is unknown. Apparently represents an invading stock, immigrant into the Cuyama Valley district. Radically different from all previously described astrodapses by reason of its highly pentagonal outline, markedly depressed center, and ultra-raised, distally humped petals. This extremely specialized clan is the most unstable and rapidly evolving one observed, one species commonly changing to another in from 10 to 30 feet of strata through the upper Cierbo. Its lower Neroly descendants were slightly more stable, their average range rising to about 50 feet. Known range of the particular variety: mid-upper Cierbo.

FIG. 3.—*Astrodapsis johnsoni* Grant and Eaton, n. sp. Holotype. Spec. 8805. U.C.L.A. loc. 1748. Has the clan attributes of *A. gregerseni* var. *fragilis*, from which latter it is easily distinguished by its even more depressed center and its elevated, inflated petals which in profile exhibit an even curvature, the greatest elevation being approximately midway between the proximal and distal ends. Known range: mid-upper Cierbo. Named in honor of Harry R. Johnson.

FIG. 3a.—*Astrodapsis johnsoni* var. *simile* Grant and Eaton, n. var. Holotype. Spec. 9210. U.C.L.A. loc. 1711. Occurs 10 feet below *A. johnsoni*, from which it differs in having a smaller size, petals which are less extremely raised, and a less extremely depressed center. Known range: mid-upper Cierbo.

FIG. 4.—*Astrodapsis gregerseni* Grant and Eaton, n. sp. Holotype. Spec. 8810. U.C.L.A. loc. 1717. Differs from its variety *fragilis* in having petals of essentially uniform elevation except at their distal ends where they round off uniformly and gradually to the ambitus. This characture is distinctly different from the distally humped petals of the variety *fragilis*. Known range: mid-upper Cierbo. Named in honor of Albert I. Gregersen, who first recognized the importance of the Bitter Creek echinoid section and called it to the attention of the sponsors before their field work reached this area.

FIG. 5.—*Astrodapsis desaixi* Grant and Eaton, n. sp. Holotype. Spec. 8815. U.C.L.A. loc. 1748. Nearest affinities are with *A. johnsoni*, from which it differs in having lower, broader petals which are more distinctly poriferous and which slope more gradually to the ambitus. Lacks the ridged petals of *A. goudkoffi*. Known range: mid-upper Cierbo. Named in honor of Desaix B. Myers.

FIG. 6.—*Astrodapsis goudkoffi* Grant and Eaton, n. sp. Holotype. Spec. 8830. U.C.L.A. loc. 1644-A. Intermediate between *A. johnsoni* and *A. englishi*. Differs from the former in having petals subangular in cross section which gives them a ridged aspect, and a less depressed center. From the latter in its prominently ridged, subangular petals, and more depressed center. Known range: mid-upper Cierbo. Named in honor of Paul P. Goudkoff.

FIG. 7.—*Astrodapsis englishi* Grant and Eaton, n. sp. Holotype. Spec. 8825. U.C.L.A. loc. 1791. Differs from *A. goudkoffi* in having only a slightly depressed center, and more nearly parallel-sided petals which are roundly convex rather than medially ridged. From its probable descendant *A. davisi* in its more pentagonal outline and less evenly rounded ventricosity of petals. Varies in outline from pentagonal to subpentagonal. Differs from all known Miocene astrodapses except *A. goudkoffi* in the extreme prominence of the ambulacral plates, which appear as fine transverse striations in high relief over the entire ambulacral surfaces in even the best preserved specimens. Known range: mid-upper Cierbo. Named in honor of Walter A. English.

FIG. 8.—*Astrodapsis gregerseni* var. *varians*, Grant and Eaton, n. var. Holotype. Spec. 8830. U.C.L.A. loc. 1711. Differs from *A. gregerseni* in having a relatively undepressed center, a less ultra-pentagonal outline, and usually sloping petals which become low toward the ambitus. Some variants are markedly pentagonal. A rather variable form which appears in pentagonal outline with the variety *fragilis*, and becomes more rounded toward the top of its relatively long range. Pentagonal variants resemble *A. margaritanus* of the lower Neroly, but have a thinner test and broader petals of distally more nearly sustained height. Differs from *A. major* and its varieties of the Neroly in having a pentagonal to subpentagonal outline of test, and petals which are less flat-topped. Known range: mid- and late upper Cierbo.

FIG. 9.—*Astrodapsis quaylei* Grant and Eaton, n. sp. Holotype. Spec. 9215. U.C.L.A. loc. 1752. The earliest known *Astrodapsis* which is very prominently tuberculate. Petals vary from very slightly (as in the holotype) to markedly obovate in outline. Differs from the superjacent *A. davisi* in having petals commonly more obovate, and in being prominently tuberculate. From *A. blakei*, which highly obovate-petaled specimens otherwise resemble, in having a test thicker both medially and at the ambitus. From the more prominently tuberculate *A. woodringi* in having a medially lower test, thicker ambitus, and an absence of deep notches at the bivium. Known range: mid-upper Cierbo. Named in honor of Ernest H. Quayle.

* Superposition for the forms in Plate VI appears to be, reading upward, *A. cutleri*, then 80± feet with oyster reefs, then, at consecutive positions averaging about 10 feet each, *A. gregerseni* var. *fragilis*, *A. gregerseni*, *A. goudkoffi* and *A. englishi*, *A. johnsoni* var. *simile*, *A. englishi* (large variant), *A. johnsoni*, *A. desaixi*, *A. quaylei*. Variants of *A. gregerseni* var. *varians* occur through the upper Cierbo above *fragilis*.

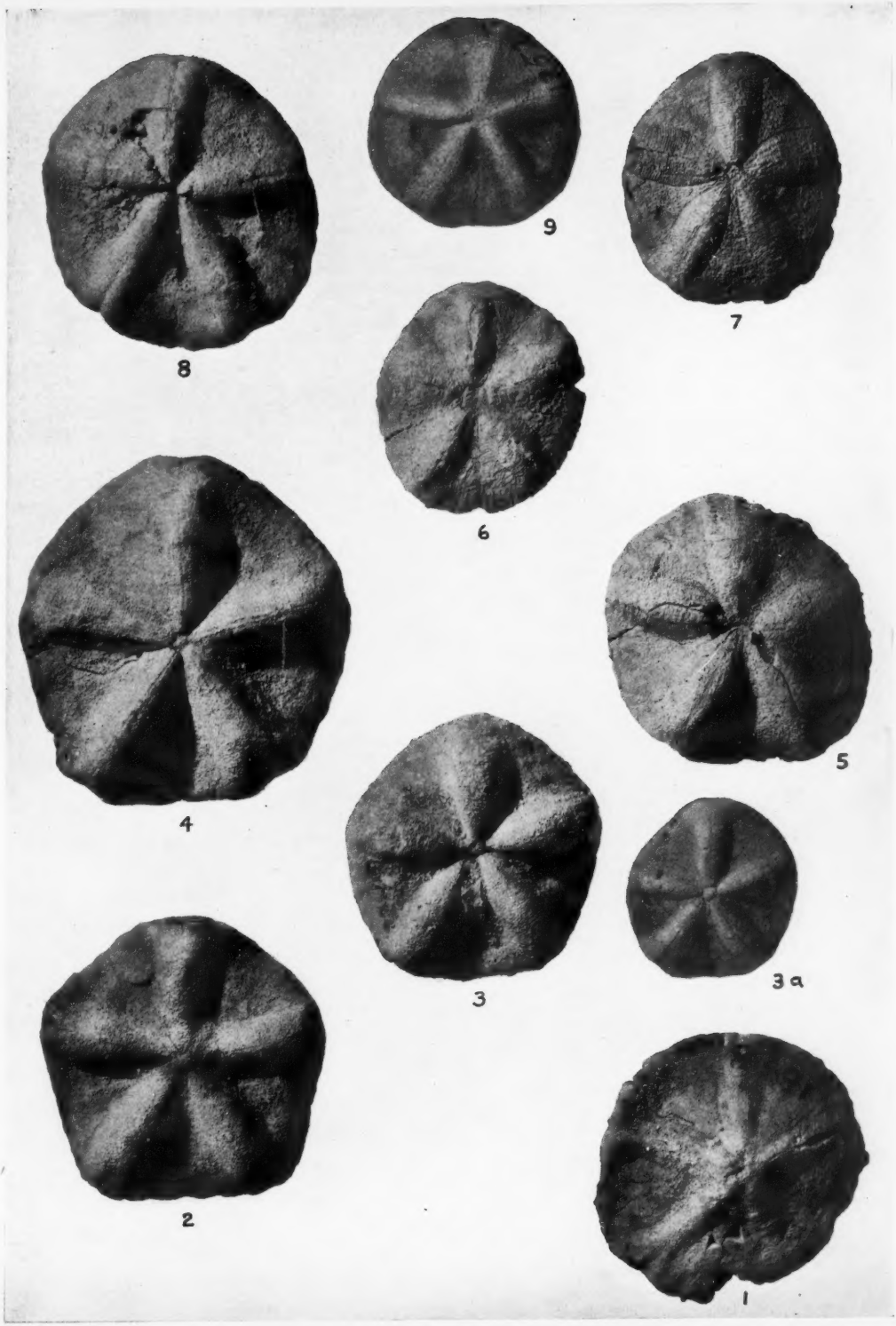

PLATE VI

EXPLANATION OF PLATE VII

Upper Cierbo and lower Neroly astrodapses, natural size, arranged in approximate superposition

FIG. 1.—*Astrodapsis clarki* Grant and Eaton, n. sp. Holotype. Spec. 8835. U.C.L.A. loc. 1755. This representative of a distinct clan, apparently another immigrant stock into the Cuyama Valley district, of unknown immediate ancestry, is radically different from all other known astrodapses by reason of its extremely wide, moderately raised and broadly obovate petals which are completely open at their ends. Test slightly subpentagonal; margin slightly notched. Its only known near relative is *A. isabellae*, from which it differs in its much thinner test and markedly lower petals. Known range: late upper Cierbo. Named in honor of Bruce L. Clark.

FIG. 2.—*Astrodapsis isabellae* Grant and Eaton, n. sp. Holotype. Spec. 8840. U.C.L.A. loc. 1791. A graceful species having one of the relatively highest tests known, whose ultra-broad petals occupy almost the entire upper surface. Differs from *A. clarki*, its only known near relative, in the very narrow spaces separating the petals in the apical region, its much higher petals, and excessively high test. Known range: late upper Cierbo. Named in honor of the late Mrs. Isabella W. Blaney.

FIG. 3.—*Astrodapsis davisi* Grant and Eaton, n. sp. Holotype. Spec. 8845. U.C.L.A. loc. 1729. Differs from its probable ancestor *A. englishi* in having a larger average size, a nearly oval instead of subpentagonal outline, and petals which are elevated by means of a gradual slope from the interambulacral surface instead of rising abruptly at the margins of the ambulacra and on which the ambulacral plates are much less prominent. From *A. major* var. *parens* of the lower Neroly in having broader petals which are not flat-topped. Known range: late upper Cierbo. Named in honor of Elmer F. Davis.

FIG. 4.—*Astrodapsis margaritanus* Kew. Spec. 8850. U.C.L.A. loc. 1843. Imperfect specimens may be confused with pentagonal variants of the related *A. gregerseni* var. *varians* from the upper Cierbo. Differs from these in its thicker test, larger size, and petals of distally less sustained height which merge with the margin. Several variants have been collected; the one figured has somewhat broader petals than the cotype figured by Kew. Known range: early lower Neroly.

FIG. 5.—*Astrodapsis cuyamanus* Kew. Topotype. Spec. 8855. U.C.L.A. loc. 1859. Kew's type specimen, obtained from the Bitter Creek district, excellently represents characteristics of this species, but illustrates a variant somewhat broader of petal, more pentagonal in outline of test, and more deeply notched at the ambitus than is average. The topotype here figured, which occurs with the typical form, illustrates a more common variant, and may therefore be considered as supplementary to the type. A small, here unfigured and undescribed variety has also been noted. Known range: early lower Neroly.

FIG. 6.—*Astrodapsis major* var. *parens* Grant and Eaton, n. var. Paratype. Spec. 8860. U.C.L.A. loc. 1714. Specimen here figured is immature, the adult size being about that of *A. margaritanus*. Apparently ancestral to the later, typical *A. major*, from which it differs in lacking the pronounced interambulacral valleys of the latter, and in having less highly raised petals. Known range: early lower Neroly.

FIG. 7.—*Astrodapsis blakei* Grant and Eaton, n. sp. Holotype. Spec. 8865. U.C.L.A. loc. 1718-A. This species differs from *A. clarki* in having narrower, lower petals, a smaller size, and in being prominently tuberculate. Differs from *A. cuyamanus* in its smaller size, prominent tubercles, much lower test normally lacking the faint bell shape, and a relatively broader, more curved outline of petals. From *A. tumidus* in its larger size, more oval outline of petals, and prominent tubercles. Known range: early lower Neroly. Named in honor of William P. Blake, one of the first master geologists to explore California, and the father of stratigraphic geology in the state.

6

7

4

LOWER NEROLY

5

UPPER CIERBO

1

2

3

EXPLANATION OF PLATE VIII

Nearly contemporaneous lower Neroly astrodapses, natural size

FIG. 1.—*Astrodapsis woodringi* Grant and Eaton, n. sp. Holotype. Spec. 8870. U.C.L.A. loc. 1852. A prominently, profusely tuberculate species with (when adult) a high central region, moderately depressed apex, high, sloping petals, subpentagonal outline, thin margin, and prominent marginal notches at the bivium. All of these features except the tuberculate nature become progressively and markedly accentuated with age. The adult here figured is close to average. (When young the test is relatively flat, more rounded in outline, and the margin is proportionately less thin; with relatively low petals, and notches which are less distinct.) Known range: early lower Neroly. Named in honor of Wendell P. Woodring.

FIG. 2.—*Astrodapsis tumidus* Remond. Spec. 8875. U.C.L.A. loc. 1728-A. Several more or less distinct species were formerly grouped under this name, causing the *sensu stricto* form to be recorded in the literature as having a much longer range than it may actually have. Kew segregated *A. major* from it. *A. blakei* has previously been confused with it, as possibly other species ranging above or below the typical form have been. Known range: mid-lower Neroly.

FIG. 3.—*Astrodapsis whitneyi* Remond. Spec. 8880. U.C.L.A. loc. 1844. Grades downward toward *A. cuyamanus* and upward toward *A. grandis*, but the partly contemporaneous existence of the three species shows that they were perhaps not direct outgrowths one of another but were rather successive branchings from some common ancestor of the Cierbo-Neroly interval. Known range: lower Neroly.

FIG. 4.—*Astrodapsis laimingi* Grant and Eaton, n. sp. Holotype. Spec. 8885. U.C.L.A. loc. 1797. Test subpentagonal in outline with high central region, petals highly raised and nearly parallel-sided, and interambulacral areas broadly concave. Related to the younger *A. californicus*, from which it differs in having a higher central region, higher petals, thicker margin, and much smaller size. Known range: mid-lower Neroly. Named in honor of Boris Laiming.

FIG. 5.—*Astrodapsis grandis* Kew. Spec. 8890. U.C.L.A. loc. 1718. Immature specimen (about half grown). A giant species related to the smaller *A. whitneyi* of common ancestry. Known range: this and another variant are early lower Neroly at Bitter Creek; the typical variety, which has not been observed here, is from its type associations presumably late lower Neroly.

FIG. 6.—*Astrodapsis perrini* Grant and Eaton, n. sp. Holotype. Spec. 8895. U.C.L.A. loc. 1853. Characterized by broad, moderately raised, rather flat-topped petals, profuse, prominent tubercles, and shallow radial gutters in the medial portion of the interambulacra. The broad, flat-topped petals vary from highly obovate to nearly parallel-sided in outline, the holotype representing an average. Superficially resembles the upper Cierbo species *A. clarki*, but differs from this in its larger size, higher petals, prominent tubercles, and in having shallow interambulacral gutters. Differs from the faintly guttered *A. laimingi* in its larger size, lower, broader petals, and larger apical disk. From the superjacent *A. californicus* in its flatter test, broader petals, and thicker margin. Known range: mid-lower Neroly. Named in honor of the late James Perrin Smith.

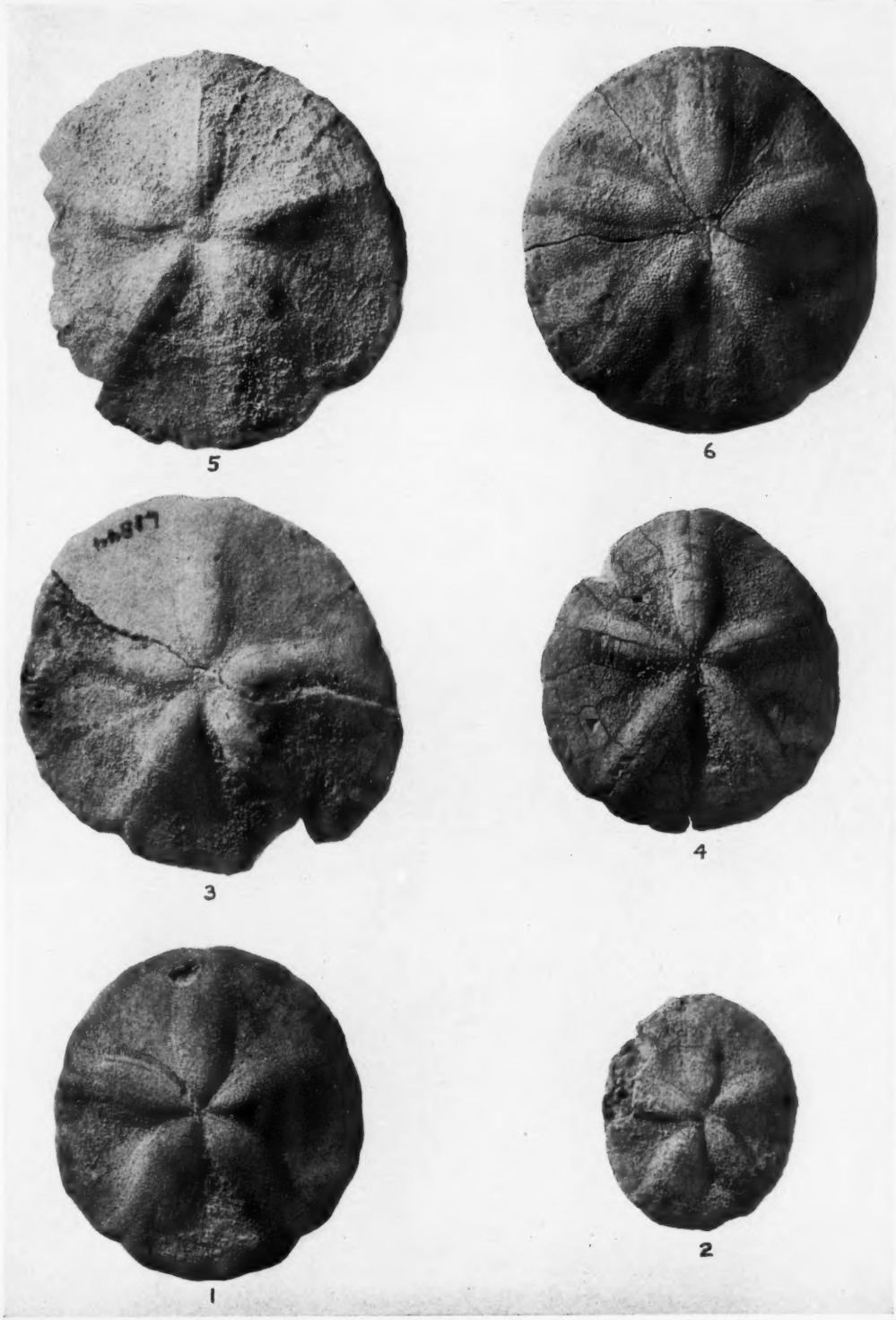

PLATE VIII

EXPLANATION OF PLATE IX

Late lower and early upper Neroly astrodapses, natural size

FIG. 1.—*Astrodapsis californicus* Kew. Spec. 8900. U.C.L.A. loc. 1721. Occurs near the top of the lower Neroly, between *A. tumidus* below, and *A. coalingaensis* and *A. hertleini* above. Known range: late lower Neroly.

FIG. 2.—*Astrodapsis hertleini* Grant and Eaton, n. sp. Holotype. Spec. 8910. U.C.L.A. loc. 1719. This handsome lower Neroly species has some affinities with *A. englishi* and *A. davisi* of the upper Cierbo, but the test is more nearly round, the margin more deeply notched, and the size much greater than in these older forms. Apparently related to the subjacent *A. californicus*, from which it differs in that the poriferous areas of the ambulacra distally converge less, it has a more distinct ambulacral flare near the ambitus, and practically flat interambulacra. Differs from the contemporaneous *A. coalingaensis* in having considerably more raised, relatively parallel-sided petals, and being of larger size. Known range: late lower Neroly. Named in honor of Leo G. Hertlein.

FIG. 3.—*Astrodapsis coalingaensis* Kew. Spec. 8905. U.C.L.A. loc. 1720. The typical, narrow-petaled form. Known range: late lower Neroly.

FIG. 3a.—*Astrodapsis coalingaensis* Kew. Spec. 8909. U.C.L.A. loc. 1719. Broad-petaled variant, found with, and more abundant than the typical form, into which it grades.

FIG. 4.—*Astrodapsis schencki* var. *mirandaensis* Grant and Eaton, n. var. Holotype. Spec. 8925. U.C.L.A. loc. 1776 (West Miranda Canyon). Differs from *A. schencki* in its extremely thin margin. Also, *A. schencki* appears to have more pronounced interambulacral gutters. Presumably either an ancestor or descendant of that form, but which, is unknown. Known range: early upper Neroly; that is, near extreme top of Miocene series.

FIG. 4a.—*Astrodapsis schencki* var. *mirandaensis* Grant and Eaton, n. var. Paratype. Spec. 8929. U.C.L.A. loc. 1776 (West Miranda Canyon). An extreme variant of the most highly specialized and variable known species of *Astrodapsis*. Occurs with, and grades into, the typical form of the variety.

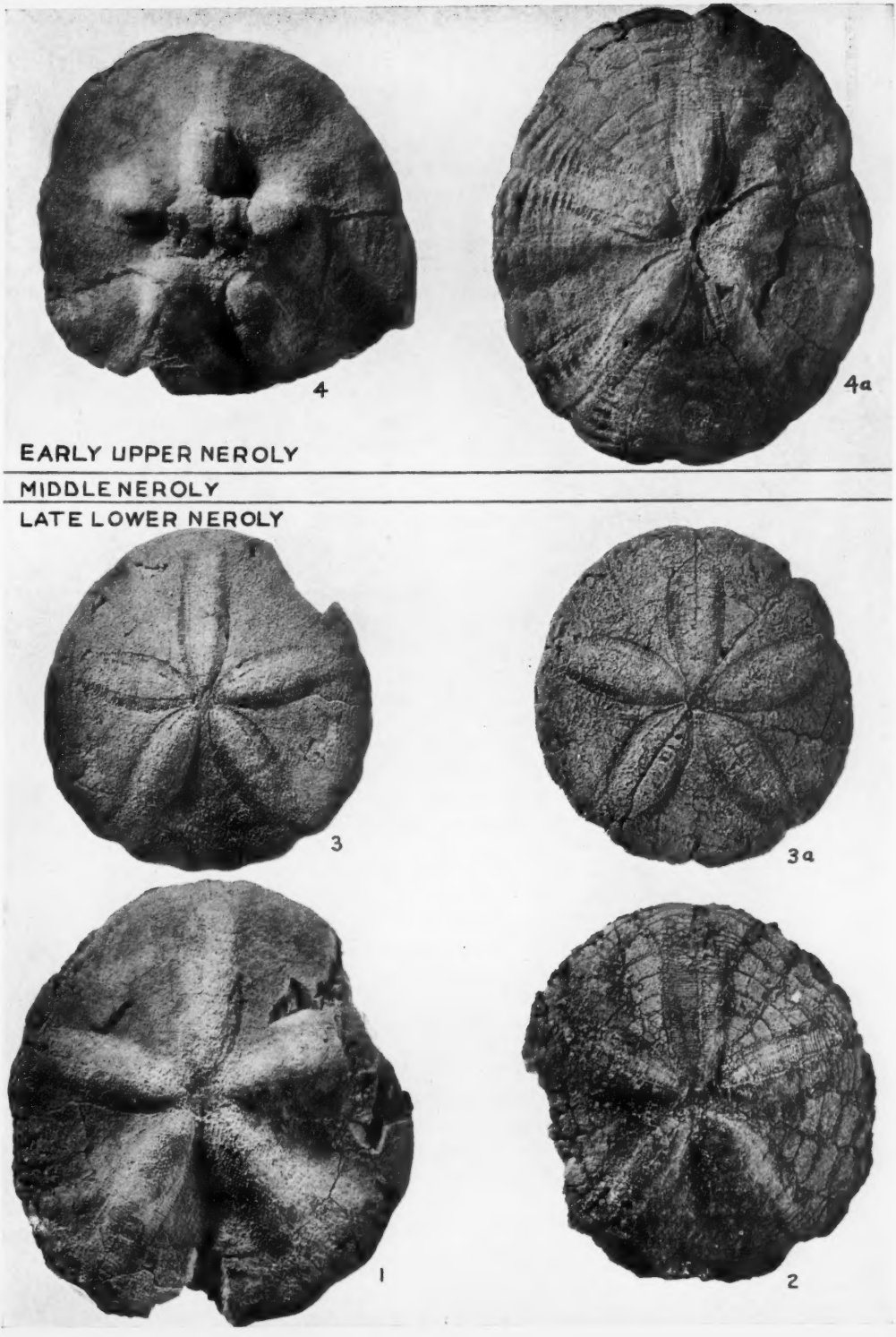
4
4a
EARLY UPPER NEROLY
MIDDLE NEROLY
LATE LOWER NEROLY
3
3a
1
2

PLATE IX

coarse, reddish yellow fans from the Sierra Madre Range spread over the older succession. These are particularly well developed in the western half of Cuyama Valley southwest of Cuyama River. Although a hundred or more feet thick near the mountains, as in upper stretches of Deadman and Cottonwood canyons, their cubic content totals only a small fraction of that of the older succession, and they presumably represent a much shorter time. Their coarseness and feather edges suggest that the current re-elevation of California was on its way; that Cuyama River had by then begun to increase its grade and was again carrying most of the finer supplied material to the sea. This younger succession, forming a nearly continuous band near the Sierra Madre Range, is present on most ridges between canyons of the west as a thin reddish yellow veneer capping the older succession and its partly contemporaneous lake deposits. On the east it forms a veneer over the broad, older fans of that locality.

All the late upper Pleistocene deposits described have been dissected by canyons several hundred feet deep in uppermost Pleistocene and Recent time, as a result of the late, partial recovery in elevation of California which rejuvenated Cuyama River. The various relations suggest that the older, greater alluvial fans represent the subsidence that occasioned the invading Terrace sea of the coastal region, and that the younger, lesser fans represent the early part, and the dissection the later part, of recovery in elevation. Dissection of the two-phase alluvial deposits has proceeded under irregular uplift which has resulted in a series of terrestrial benches that resemble, and are assumably diastrophically related to, the coastal marine terraces.

Pleistocene degradation.—The time represented by the deposition and partial removal of the alluvial deposits is appreciable. Yet it can represent only the last few per cent of Pleistocene time as a whole, for the Pliocene(?) beds were evidently laid down as a sheet fill over what is now Cuyama Valley, Caliente Range, and Carrizo Plain, and the late alluvial deposits were spread in a subsequent prepared valley eroded thousands of feet between ranges of partly indurated rocks. These ranges were degraded prior to deposition of the alluvial deposits an average of more than 10,000 feet in older parts of the Pleistocene epoch of revolution (see cross section, Fig. 3).

TRANSGRESSION AND REGRESSION

The often quoted generalization that a complete sedimentary cycle at a locality is a triplet composed of transgressive and regressive phases each of coarser, and an intervening flood phase of finer local deposition is perhaps sound in theory, but if in practice deductions are

made from it without considering qualifying factors conclusions contrary to the facts may result. Though usually applicable in California, exceptions exist. Thus, the restricted Oligocene(?) of Caliente Range, which in unqualified theory should be much coarser than the more widespread Vaqueros conformably overlying it, is in reality finer, apparently due in part to the qualifying feature that in the Oligocene(?) adjacent lands were evidently low and nearly base-leveled whereas the subsequent lower Miocene saw tributary lands with more relief.

The widest advance of Miocene seas in the state rather definitely occurred during the Neroly substage (late upper Miocene), for at such widely separated regions as San Pablo Bay, the Coalinga district, the environs of Caliente Range, the Santa Maria district, Ventura Basin, *et cetera*, strata of this age transgress all previous Miocene deposits and overlap pre-Miocene rocks. Yet Neroly sediments, due to the qualifying factor that they followed immediately after a sharp diastrophic movement between the Cierbo and Neroly, are locally so coarse that in blind adherence to the tripartite rule the substage has been held by some to have been a time of regression. This again reflects the early belief that there was a universal sheet of Monterey "shale" overlain by such a sheet of Santa Margarita "sand," whereas it has for some time been apparent that such textures are but local facies that interfinger in short distances.

Regressive phases are ofttimes in large part unrepresented by sediments in California if appreciable unconformity is involved, because at or near their inception the profile of equilibrium, under the resulting local overload, tended to cause a local total passing of particles, which latter phenomenon followed by subsequent erosion has resulted in regressive phases being locally unrepresented. It is concluded that transgression, regression, and the extent of ancient seas in California are best determined by mapping ancient strands.

PRESENT STRUCTURE

Present structure of the post-Eocene in most parts of the district is chiefly a result of the profound Pleistocene diastrophism which highly deformed California, for in Caliente Range, Carrizo Plain, and southern Cuyama Valley the Miocene and Pliocene(?) series dip steeply at nearly the same angle. On fringes of the trough, as in strandward parts of Cuyama Valley, moderate diastrophism within the Miocene, and between the Miocene and Pliocene(?), is reflected by locally perceptible differences in dip between the Temblor and the Monterey, between the middle and upper Monterey (Cierbo and Neroly substages), and between the Monterey and the Pliocene(?). The last of these discontinuities, that between series, is relatively

large. For the district as a whole, approximately 80 per cent of the post-Eocene deformation is indicated to have occurred in the Pleistocene, which is close to the average for California. At least 90 per cent of the total average degradation of the post-Eocene marine deposits appears to have occurred in Pleistocene time, as, except for a possible barely emergent ridge reflecting the incipient Caliente Range folds, and perhaps on extreme fringes of the trough, the district is known to have undergone widespread continental deposition in the Pliocene(?).

The district is at present a highly deformed region in which most dips range from 30° to vertical, with belts of overturned strata along thrust zones. The larger anticlines are deeply eroded. Those in Caliente Range are locally overthrust southwestward toward Cuyama Valley. In this range the post-Miocene degradation, nearly all of which for reasons given seemingly represents Pleistocene erosion, ranges from a maximum of about 16,000 feet at Caliente Mountain to a minimum of about 9,000 feet at certain transverse structural lows as regards the axial folds. Carrizo Plain and Cuyama Valley are heavily faulted along both of their flanks in the territory shown on the accompanying map. In western Cuyama Valley the Cretaceous(?) system is strongly deformed, but the comparative thinness of the Tertiary cover there causes this latter system locally to have relatively gentle attitudes. Southern edges of this valley expose tightly compressed folds, and, locally, large thrusts. The structure of much of the broad upper Cuyama Valley is concealed by alluvium and alluvial fans, as is that of large parts of Carrizo Plain.

Caliente Mountain thrust fault.—The thrust zone along the southwestern foot of Caliente Mountain illustrates all stages of thrusting from an overturning anticline, through an initial break, and then on to a major thrust sheet. It presents the best locality for studying the mechanics of thrusting that the writers have so far observed.

Caliente Range is composed of several anticlines arranged *en échelon* which apparently formed slightly southwest of the axis of maximum Tertiary subsidence and deposition. These anticlines have been strongly thrust southwestward, by pressure from the northeast, toward Cuyama Valley. The resistance exerted by the consolidated Cretaceous(?) rocks beneath the relatively thin Tertiary cover of Cuyama Valley has caused the anticlines to overturn and locally break along their southwestern flanks, with the result that a series of thrust faults arranged *en échelon* has developed. This local series is but a small part of the great thrust arcs in Southern California that extend 50 miles south and southwest from the bending San Andreas rift.

The Caliente Mountain thrust fault is opposite the deepest part of the Caliente trough, the feature that it is perhaps the largest of the

local thrusts being seemingly due to this circumstance. The initial break in the overturning Caliente Mountain anticline is indicated to have occurred a short distance southwest of its present high point; that is, slightly down the overturning southwestern flank. The maximum present throw occurs at this locality. The thrust here cuts out about 3,000 feet of strata, the upper Vaqueros resting, in Scarp Canyon, against the lower part of the *Baggina robusta* zone.

From the focal point in Scarp Canyon, which forms a reëntrant due apparently either to some resistance that determined this point or to a larger slippage and therefore a local relief of pressure there, two arcuate wings curve northwest and southeast (Fig. 3), their throws decreasing outward. The throw of the northwest wing declines in the two miles between Scarp and Pinnacle canyons to about 2,000 feet, the upper Vaqueros resting against the *Uvigerinella obesa* zone of the middle Temblor at the latter locality, and dies out completely in another two miles or less. The southeast wing has a more or less sustained throw of about 3,000 feet for 1½ miles, at which distance from Scarp Canyon the lower Temblor almost touches the *Valvulineria californica* zone. The wing then passes under terrace deposits, but is indicated by the mapped relations to die out, on an arcuate course, 5 or 6 miles from the focal center.

The strata on both sides of the thrust stand from vertical to overturned throughout its visible course, having practically the same dips on both sides. This latter feature causes the trace of the thrust to be generally inconspicuous, even where it cuts diagonally across the strike, though the convergence of horizons is locally marked. Both the overriding and overridden strata are cut out along the northwestern wing, while along the southeastern wing the overriding strata emerge and slide farther over the overridden flank.

A secondary, lesser, parallel thrust is present about ½ mile mountainward. At its focal point, also in Scarp Canyon, this secondary thrust is between the lower and upper Vaqueros, and cuts out a middle 1,000 feet of this stage. Northwestward the throw disappears within 2 miles at or near Pinnacle Canyon. Immediately east of Scarp Canyon the trace is somewhat obscured by landslides, but it appears to cut into or across the Oligocene(?) dark silt, and then possibly underneath the landslides, the throw becoming negligible in less than a mile. The southeast wing, though shown on Figure 3 as a break, is at present little more than a knife-edge overturning fold. Allowing for a computed 30 per cent thinner section on the southwest flank than on the northeast flank of the Caliente Mountain anticline, the maximum amount of strata cut out by the combined primary and secondary thrusts totals about 4,000 feet, this maximum being in Scarp Canyon.

Southeast of the Caliente Mountain thrust other thrusts, visible or indicated by overturning along the alluvial edge of Cuyama Valley, lie *en échelon* and relieve the strain.

Morales Canyon thrust fault.—Northwest of the Caliente Mountain thrust, the Morales Canyon thrust fault, lying *en échelon* with and overlapping the former, gradually assumes the task of relieving pressure. The latter thrust increases its throw northwestward in the direction that the former thrust decreases.

Whiterock thrust fault.—This, in turn, relieves the compressive strain. It approaches or equals in magnitude the Caliente Mountain thrust, for basal Temblor or upper Vaqueros locally overrides Pliocene(?), but the column is thinner here. The lateral override seems to have been a mile or more, since one flank of a large syncline is cut out, and the columns separated by the thrust have markedly different thicknesses. This thrust has not been traced northwest from Taylor Canyon, and to what extent it continues in this direction is at present unknown.

Cuyama fault.—This roughly parallels a smoothed course for Cuyama River southeasterly from Carrizo Canyon. It is doubtfully traceable from scattered exposures and stratigraphic relations to a point a little southwest of the Caliente Ranch buildings. East of the latter a series of springs and swamps along alluvial bluffs may reflect a buried course, but normal drainage from a laterally truncated broad alluvial fan is an alternate explanation for this aqueous line.

Nacimiento fault zone.—A line of nearly, but not quite, continuous faulting forms the southwest boundary of Cuyama Valley and separates this valley from the Sierra Madre Range, which latter is locally overthrust toward the valley. According to Gregersen, and Reed and Hollister, this is a local division of the long Nacimiento fault zone, which they believe separates regions having respectively Franciscan and granitic basement rocks. Because of regional values this faulting should be referred to as the Cuyama division of the Nacimiento fault zone, and not be confused with the Cuyama fault proper of Cuyama Valley.

PROSPECTS FOR THE OCCURRENCE OF OIL AND GAS IN COMMERCIAL AMOUNTS

Eleven wells seeking oil or gas have been drilled in the area covered by Figure 3, and several more in Carrizo Plain northwest of this map, so far without success. Few of these have been located favorably as regards structure.

Conditions in the district do not appear favorable for the occurrence of major pools of oil or gas, there being a seeming absence of large anticlines having sealed reservoir beds above a generative series.

It is quite possible, however, that small or moderate accumulations of a commercial nature may ultimately be found. Two oil seeps have been observed by the writers; one in basal Temblor strata of Caliente Range about 2½ miles north of Cuyama Ranch headquarters, and the other in Monterey strata in the bed of Cuyama River near Whiterock Bluff. Arnold and Johnson[59] report an outcrop of oil sand in Secs. 14 and 23, T. 29 S., R. 17 E., M.D.B. & M., northwestern Carrizo Plain.

The problem in the district is not to find closed anticlines, for many occur, but to find such that are not so deeply eroded and fractured that any oil and gas once contained has escaped. Of the three largest anticlines in Caliente Range, that at Caliente Mountain is domal but is eroded into the Oligocene(?) and thrust southwestward over most of the Temblor. Another farther east is domal but is eroded half way through the Vaqueros. The easternmost anticline is eroded deep into the Oligocene(?), is faulted on both flanks, and closure is not certain.

Southeastern Carrizo Plain is less eroded, but appears to be badly fractured. Northwestern parts of this plain are somewhat but less broken, and have a number of closed anticlines in and northwest of Figure 3 which retain an appreciable thickness of the original Miocene cover.

Western Cuyama Valley is deeply eroded north of Cuyama River. Southern edges of this valley are strongly compressed and faulted. The stratigraphy and structure of broad eastern parts having an alluvial cover is unknown.

INVESTIGATION INCOMPLETE

Over periods of respectively 12, 7, and 3 years the writers have averaged a few days of field work each season in the district discussed, mostly as occasional week ends. It was early recognized that due to a combination of factors such as rarely occurs in nature this small region provides a maximum stratigraphic, structural, and faunal record for the Miocene; that in a few miles nearly every facies of the series, physical and faunal, marine and continental, is visible in a manner not elsewhere available; and that the whole, situated like the hub of a wheel between major basins of the state, affords an unsurpassed control section for the Miocene.

Except for parts of the Bitter Creek area, field work by the writers represents on the whole only a rapid reconnaissance. Circumstances which seem to preclude a more full investigation on their part have led them to issue the present outline for the purpose of calling attention to the district and providing a preliminary framework for future investigation.

[59] Ralph Arnold and H. R. Johnson, *op. cit.*, p. 215.

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VOL. 25, NO. 2 (FEBRUARY, 1941), PP. 263-286, 3 FIGS., 2 PLS.

MICROPALEONTOLOGY AND STRATIGRAPHY OF A DEEP WELL AT NICEVILLE, OKALOOSA COUNTY, FLORIDA[1]

R. HENDEE SMITH[2]
University, Louisiana

ABSTRACT

In the type area of the Florida upper and middle Miocene section there is still considerable doubt as to the thickness and dip of the beds and the ranges of many of the microfossils. Drilling of a water well in the southern part of Okaloosa County has made it possible to establish some strike and dip control of the formations in addition to first occurrences of some typical forms in the column. It serves as a useful point of departure for correlation of wells in other parts of the Gulf Coast, as it aids in establishing the relative position of points on the paleontological time scale, which previously were known only from inferential evidence.

INTRODUCTION

A water well was drilled to a depth of 524 feet at the Jackson Ranger Station at Niceville, Okaloosa County, Florida, in April, 1939. The surface elevation was 59 feet with the measuring point 1 foot above the surface. Six-inch casing was set at 370 feet. Cuttings were taken approximately every 10 feet and saved through the courtesy of G. W. Glendenning, superintendent of construction and maintenance, United States Forest Service, Tallahassee. The cuttings were furnished the writer through the courtesy of Herman Gunter, State geologist of Florida.

STRATIGRAPHY

PLEISTOCENE

The Pleistocene is represented by samples ranging from the surface to 80 feet in depth, varying grades of coarse sands and fine gravel with some kaolin as a matrix in the lower 20 feet. There is a gradual increase in the coarseness of the materials to 50 feet with finer material below and a second maximum at 80 feet. It is possible that the two gravel bodies which were penetrated represent the basal gravels of two different Pleistocene terraces.

PLIOCENE-MIOCENE?

Materials from 80–120 feet consist of very fine, gray, unfossiliferous sand. This sand is difficult to date in the absence of fossils, but since it resembles the foraminiferal material below lithologically it is assumed to be marine. Since no unit younger than the *Ecphora* zone

[1] Read before the Society of Economic Paleontologists and Mineralogists at Chicago, April 11, 1940. Manuscript received, July 19, 1940.

[2] School of Geology, Louisiana State University.

of the Choctawhatchee formation has been recognized below it, this sand may possibly represent the *Cancellaria* zone of the Choctawhatchee. Such an assignment of age is, however, purely tentative. There is a possibility that this material is Pleistocene and accordingly, in the cross section (Fig. 2), this material has been included with the Pleistocene.

MIOCENE

From 120 feet, where the first Foraminifera appear, to the bottom of the well at 524 feet the section penetrated appears to be Miocene. From 120 feet to 346 feet the samples consist of gray to greenish gray foraminiferal marls and fine sands with slightly more sand in the lower 50 or 60 feet.

Choctawhatchee formation.—The fauna first encountered in the sample from 120–135 feet is suggestive of that found in the Permenter's Farm beds, locality 25. This fauna is assigned by Cushman and Ponton[3] following Mansfield[4,5] to the *Ecphora* zone of the Choctawhatchee formation. Additional species are found in the samples between 135 and 194 feet, but there is nothing that is recognizable as being older than the Permenter's Farm beds. *Dentalium carolinense* Conrad, a form that is said by Mansfield[6] to be confined to the *Ecphora* zone, is found in the sample from 161–172 feet.

In the sample from 204–214 feet *Siphogenerina lamellata* Cushman and *Plectofrondicularia floridana* Cushman make their first appearance. This is taken as indicating that the top of the *Arca* zone of the Choctawhatchee was encountered between these depths. In the interval from 204 to 346 feet *Cytheretta* cf. *C. spencerensis* Smith, *Nodogenerina advena* Cushman and Laiming, and *Phacoides flumenvadosa* Gardner suggest that the *Yoldia* zone of the Choctawhatchee formation or the Shoal River formation may have been penetrated. The writer believes, however, that the presence of these three forms is insufficient evidence for assigning any of the section 204–346 feet to any unit older than the *Arca* zone.

Oak Grove sand?—This formation is questionably represented by a gravel bed that is penetrated somewhat above 357 feet. This bed is

[3] J. A. Cushman and G. M. Ponton, "The Foraminifera of the Upper, Middle, and Part of the Lower Miocene of Florida," *Florida State Geol. Survey Bull. 9* (1938), pp. 15–16.

[4] W. C. Mansfield, "Miocene Pelecypods of the Choctawhatchee Formation of Florida," *ibid., Bull. 8* (1932), p. 22.

[5] *Idem*, "New Miocene Gastropods and Scaphopods from Alaqua Creek Valley, Florida," *ibid., Bull. 12* (1935), p. 10.

[6] *Idem*, "Miocene Gastropods and Scaphopods of the Choctawhatchee Formation of Florida," *Florida State Geol. Survey Bull. 3* (1930), pp. 138, 139.

evidently thin since the 335–346-foot sample contained no gravel and the 346–357-foot sample penetrated limestone bearing a Chipola fauna.

Chipola formation.—Somewhere between 346 and 357 feet the bit penetrated limestone which bears some sandy stringers. The following species are suggestive of the Chipola age of the lime: *Elphidium chipolensis* Cushman and Ponton, *Operculinoides* sp., *Cytheretta okaloosaensis* Smith n.sp., *Amphistegina chipolensis* Cushman and Ponton, *Cytheretta dalli* Smith n.sp., *Cytheretta calhounensis* Smith n.sp., *Sorites(?)* sp., and *Hemicythere calhounensis* Smith n.sp. Several of these species or their close analogues occur also in the Oak Grove sand but the general assemblage suggests Chipola. In the cross section (Fig. 2) the top of the Chipola is rather arbitrarily placed at 350 feet, which is in the interval occupied by the sample from 346–357 feet. The Chipola is thought to extend from 350 to 483 feet where there seems to be a slight lithologic break.

Tampa formation.—From 483 feet to the bottom of the well at 524 feet the samples consist of brownish limestone fragments with very few fossils. The only diagnostic form noted was a single fragment of what may be *Archais floridanus* in the sample from 483–492 feet.

DESCRIPTION OF SAMPLES

Feet		
0– 10	Coarse sand with a little ferruginous stain	(No fossils)
20	As above	(No fossils)
30	As above but slightly coarser	(No fossils)
40	As above but slightly finer	(No fossils)
50	As above with some fine gravel	(No fossils)
60	As above but appreciably finer	(No fossils)
70	Coarse quartz sand and some lumps consisting of fine sand bound by kaolin	(No fossils)
80	A little coarse sand, mostly fine sand bound into lumps by kaolin as above	
90	As above with addition of some lumps of somewhat consolidated sandy shale. Some pink kaoliniferous material containing lumps of cemented gray sand	(No fossils)
100	Gray micaceous very fine sand, cemented, some medium quartz sand	(No fossils)
110	As above	(No fossils)
120	As above	(No fossils)
135	Greenish gray, sandy, foraminiferal marl with marine fauna *Robulus americanus* (Cushman) *Robulus vaughani* (Cushman) *Robulus americanus* var. *spinosus* (Cushman) *Marginulina* sp. *Marginulina dubia* Neugeboren *Guttulina costatula* Galloway and Wissler *Guttulina austriaca* d'Orbigny? *Uvigerina perigrina* Cushman *Nonion pizarrensis* Berry *Reussella spinulosa* (Reuss) *Bulimina inflata* Seguenza *Bulimina gracilis* Cushman	

Feet

Bolivina plicatella Cushman
Bolivina floridana Cushman
Virgulina punctata d'Orbigny
Bolivina marginata Cushman
Bolivina marginata var. *multicostata* Cushman
Cassidulina laevigata var. *carinata* Cushman
Cassidulia crassa d'Orbigny
Globorotalia menardii d'Orbigny
Planulina depressa (d'Orbigny)
Rotalia beccari var.
Cibicides concentricus (Cushman)
Cibicides floridanus (Cushman)

150 As above, first appearance of the following
Textularia "articulata" d'Orbigny
Valvulineria floridana Cushman
Robulus floridanus (Cushman)
Robulus iotus (Cushman)?
Buliminella curta Cushman

161 As above, first appearance of the following
Gaudryina atlantica (Bailey)
Textularia mayori Cushman
Robulus iotus (Cushman)
Cythereis rugipunctata (Ulrich and Bassler)
Cytheretta sp.
Spirolplectamina cf. *S. barrowi* Cushman and Ellisor
Amphistegina sp.
Uvigerina auberiana d'Orbigny
Orbulina universa d'Orbigny
Cytheredeis ashermani Ulrich and Bassler
Cythereis americana var. *cornuta* Ulrich and Bassler
Cythereis martini var.
Hemicythere sp.
Cytheromorpha warneri Howe and Spurgeon
Phacoides trisulcatus multistriatus (Conrad)

172 As above, first appearance of the following forms
Textularia candeiana d'Orbigny
Discorbis turrita Cushman
Valvulineria floridana ? Cushman
Cythereis exanthamata var.
Cytherella sp.
Cythereis aff. *C. garretti* Howe and McGuirt
Dentalium carolinense Conrad
Phacoides sp, (young)
Phacoides parawhitfieldi Gardner

182 As above, first appearance of the following forms
Planularia ? sp. (very large form)
Cancris sagra (d'Orbigny)
Cythereis sp.
Corbula (*Carycorbula*) *nucleata deadenensis* Mansfield

194 As above, first appearance of the following forms
Orthoplecta miocenica Stephenson (MS)
Quinqueloculina seminula (Linne)
Loxistomum sp.
Operculinoides sp. ?

204 As above, first appearance of the following forms
Textularia foliacea var. *occidentalis* Cushman
Lagena striata
Frondicularia saggitula Vanden Broek
Cytheretta sp. (moult)
Virgulina fusiformis Cushman
Buliminella elegantissima (d'Orbigny)

Feet

214 As above, first appearance of the following forms
- *Sarecenaria acutauricularis* Fichtel and Moll
- *Marginulina* aff. *M. glabra* d'Orbigny
- *Siphogenerina lamellata* Cushman
- *Plectofrondicularia floridana* Cushman
- *Basslerites miocenica* (Howe)
- *Bolivina paula* Cushman and Cahill
- *Virgulina* sp.

225 As above, first appearance of the following forms
- *Cytheretta bassleri* Howe
- *Nodogenerina advena* Cushman and Laiming

236 As above, first appearance of the following forms
- *Dentalina* sp.
- *Guttulina* sp.
- *Bolivina* aff. *B. tenuistriata* Cushman and Ellisor
- *Cytherella* sp.
- *Loxostomum gunteri* Cushman
- *Uvigerina* sp. (smooth)
- *Amphistegina* sp.
- *Nodosaria* sp.
- *Nodosaria* sp.
- *Cytheretta* cf. *C. spencerensis* Smith

245 As above, nothing additional

255 As above, first appearance of the following forms
- *Phacoides flumenvadosa* Gardner
- *Cytheretta* sp.
- *Cythereis vaughani* (Ulrich and Bassler)
- *Cytheredeis* sp.

266 As above, first appearance of the following forms
- *Cytheridea* sp.
- *Cytheromorpha warneri* var. *okaloosensis* Howe and Spurgeon
- *Cytheropteron* sp.
- *Cythereis* sp.

276 As above, first appearance of the following forms
- *Bulimina* sp.
- *Anomocytheridea floridana* (Howe and Hough)
- *Cytheredeis ulrichi* Howe and Johnson
- *Cythereis producta* (Ulrich and Bassler)
- *Xestolebris* sp.
- *Cytherella* sp.

286 As above, first appearance of the following forms
- *Cytheridea* (*Clithrocytheridea* ?) sp.

295 As above, first appearance of the following forms
- *Cibicidella variabilis* (d'Orbigny)
- *Textularia* aff. *T. mississippiensis*

304 As above, nothing additional

314 As above, nothing additional, fossils rather rare

324 As above, 30–40 per cent medium sand

335 As above, some sand

357 As above, 60 per cent sand, some gravel, first limestone fragments, first appearance of the following forms
- *Elphidium chipolensis* Cushman
- *Amphistegina chipolensis* Cushman and Ponton
- *Sorites* ? sp.
- *Siphonina* sp.
- *Loxoconcha* sp.

368 Greenish gray limestone fragments, first appearance of the following forms
- *Elphidium* aff. *E. poeyanum*
- *Operculinoides* sp.
- *Cythereis* sp.
- *Cytheretta calhounensis* Smith

Feet	
	Cytheretta dalli Smith
378	As above, nothing additional
379	Soft gray limestone and fine to medium sand. Fossils rather poorly preserved
	Textularia sp.
	Robulus cf. *R. americanus* (Cushman)
	Robulus vaughani (Cushman)
	Globulina inaequalis d'Orbigny
	Cytheretta karlana Howe and Pyeatt
	Guttulina austriaca d'Orbigny
	Uvigerina perigrina Cushman
	Amphistegina chipolensis Cushman and Ponton
	Hemicythere calhounensis Smith
	Cythereis cornuta var. *americana* Ulrich and Bassler
	Cytheretta okaloosaensis Smith
	Hemicythere sp.
	Cythereis sp.
	Cancris sagra d'Orbigny
	Cytheredeis ashermani Ulrich and Bassler
	Eponides sp.
	Cythereis exanthamata var.
389	As above, no additional forms
400	As above, first appearance of the following form
	Cytherelloidea sp.
410	As above, no additional forms
420	As above, no additional forms
430	As above, no additional forms
440	As above, no additional forms
451	As above, no additional forms
462	Very porous, greenish gray, calcareous sand, no additional forms
483	Cream-colored slightly sandy limestone, no fossils
492	As above but brownish and with no sand
	Archais floridanus Cushman
504	As above, no diagnostic fossils
514	As above, no diagnostic fossils
524	As above, no diagnostic fossils
	Total depth, 524 feet

RELATION OF NICEVILLE WELL TO SURFACE SECTION

Because of the rarity and scattered nature of good outcrops in western Florida, stratigraphic work has heretofore been based almost entirely on paleontology with little attempt being made to ascertain thicknesses and amounts of dip. The Niceville well is so situated as to afford some control for calculating the thickness and dip of strata cropping out in the area shown in Figure 1. The area shown in this map is notable for containing many famous Miocene fossil localities. It is largely from outcrops in this area that geologists, notably Miss Julia Gardner,[7] of the United States Geological Survey, and the late W. C. Mansfield,[8] have set up the standard section for the middle Miocene of the Gulf Coast.

[7] J. A. Gardner, "The Molluscan Fauna of the Alum Bluff Group," *U. S. Geol. Survey Prof. Paper 142A* (1926).

[8] W. C. Mansfield and G. M. Ponton, "Faunal Zones in the Miocene Choctawhatchee Formation of Florida," *Washington Acad. Sci. Jour.*, Vol. 22 (1932), pp. 84–88.

Numbers on the map refer to the outcrops mentioned in this paper. More exact locations of these outcrops may be found in the locality list at the end of this paper. The relation of outcrops to the Niceville well is shown in Figure 2, a cross section along the line *AB* of the map (Fig. 1). Topography shown on section was derived from United States Geological Survey topographic sheets of the DeFuniak Springs and Point Washington quadrangles. All outcrops shown in the cross section have been projected in along an assumed line of strike which bears a little north of west. The north-south section of Figure 2 is thus very nearly a dip section. The extreme gentleness of the dip of the beds in this area (calculated as about 25 feet per mile) would tend to minimize any error introduced by faulty assumption as to the strike, so it may be assumed that the cross section gives a relatively good picture of conditions. The rectangular areas which designate the outcrops have been drawn to scale and represent the approximate thicknesses exposed. Elevations of outcrops are either taken from published data, or were established by the writer with an aneroid barometer.

The well shown on the map and in the section as the Rockhill well is the Walton Land and Timber Company's Rockhill No. 1. It is located 10 miles south of Defuniak Springs near the Defuniak Springs-Freeport Highway in Sec. 12, T. 1 N., R. 19 W., Walton County, Florida. Points indicated on the cross section were obtained from a report by Gerald Ponton, formerly of the Florida State Geological Survey. This report is on file in the offices of the Florida State Geological Survey in Tallahassee. These points are used in this paper through the courtesy of Herman Gunter, State geologist of Florida.

A comparison of the section employed in this paper with the "standard" section as given by Cooke and Mossom,[9] and emended by Mansfield,[10] and Cushman and Ponton[11] is shown in Table I. In this paper several new terms are used whose equivalency is shown in the table.

The name Permenter's Farm beds is proposed to designate beds that lie above the *Arca* zone beds in Walton County. The type locality is locality 25, which is in an old road-cut on the east bank of Alaqua Creek in Sec. 17, T. 1 N., R. 19 W., Walton County, Florida. About 25 feet of fossiliferous gray marl is exposed at this locality. These beds were assigned to the *Ecphora* zone of the Choctawhatchee by Mans-

[9] C. W. Cooke and Stuart Mossom, "Geology of Florida," *Florida State Geol. Survey 20th Ann. Rept.* (1929), pp. 29–227.

[10] W. C. Mansfield, "Miocene Pelecypods of the Choctawhatchee Formation of Florida," *ibid., Bull. 8* (1931), pp. 7–29.

[11] J. A. Cushman and G. M. Ponton, *op. cit*

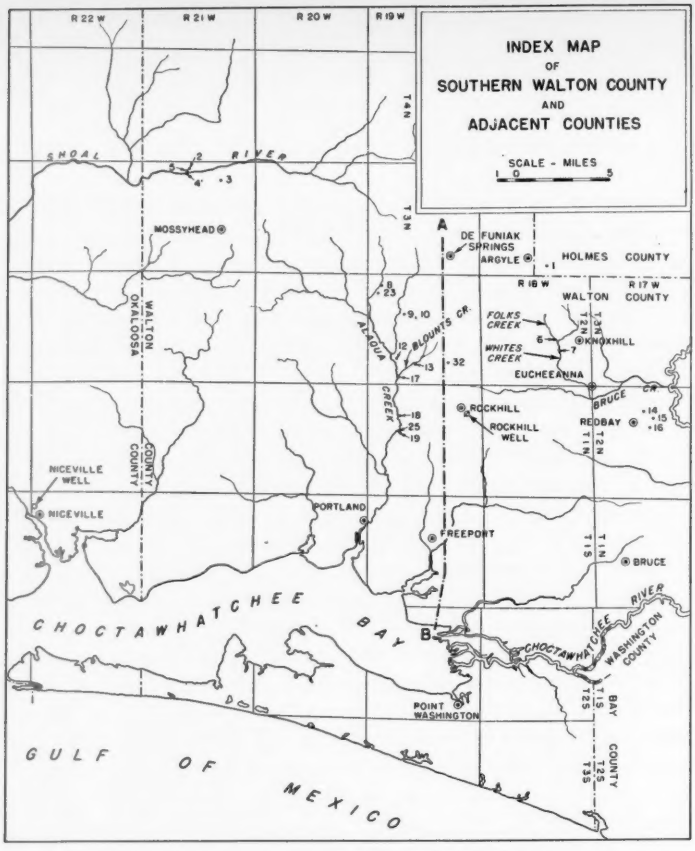


FIG. 1.—Map of area northeast of Niceville well showing location of outcrops and position of cross section *AB*.

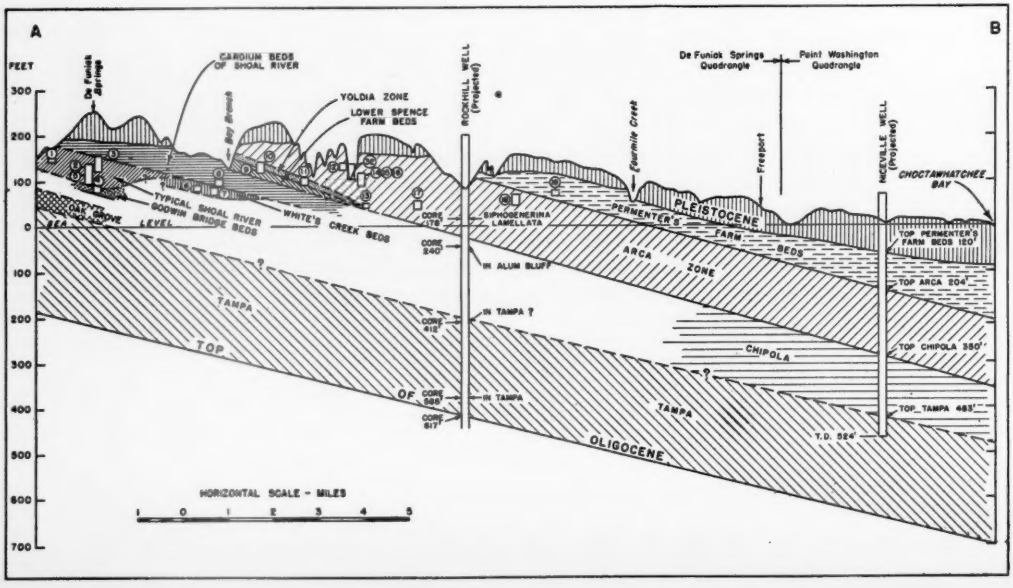


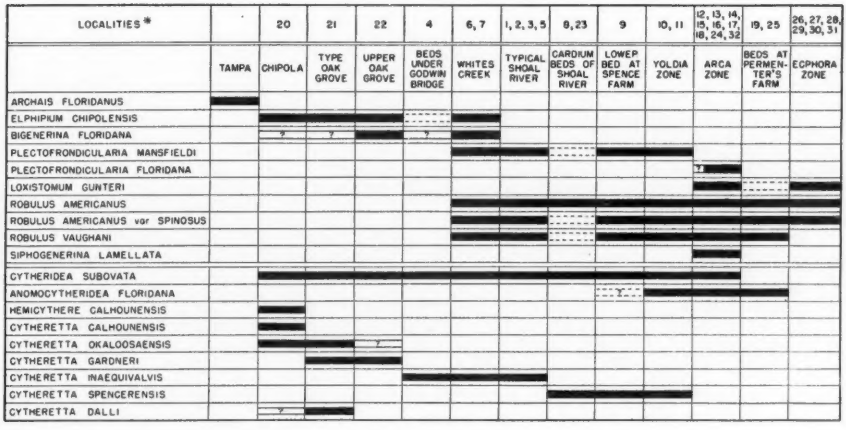
FIG. 2.—Cross section *AB*. Outcrops and wells projected in along a strike bearing a little north of west.

TABLE I

COMPARISON OF STANDARD MIOCENE SECTION OF WESTERN FLORIDA WITH SECTION USED IN THIS ARTICLE

			*Standard Section**		*Section Used in This Article*
MIOCENE	UPPER		Choctawhatchee formation	*Cancellaria* zone	*Cancellaria* zone
				Ecphora zone	*Ecphora* zone
	MIDDLE			*Arca* zone	Permenter's Farm beds
					Arca zone
				Yoldia zone	*Yoldia* zone
		ALUM BLUFF GROUP	Shoal River formation	*Cardium* bed	Lower bed at Spence farm
					Cardium beds
				Middle zone	Type Shoal River / Whites Creek beds
				Type zone	
					Godwin Bridge beds
			Oak Grove sand	Transition zone	Upper Oak Grove
				Type zone	Type Oak Grove
	LOWER		Chipola formation	Chipola	Chipola
			Tampa formation	Tampa	Tampa

* Modified from Cushman and Ponton (1932), *op. cit.*



* For description of localities see list at end of paper.

FIG. 3.—Chart showing ranges of certain diagnostic fossils in Florida Miocene. Black line indicates that form has been found at one or more of the localities at head of column.

field[12] on the basis of Mollusca. Cushman and Ponton[13] followed Mansfield in placing these beds in the *Ecphora* zone and hence in the upper Miocene. Mansfield's assignment was made chiefly on the basis of the presence of *Arca* (*Anadara*) *aresta* Dall, a form that is characteristic of the *Ecphora* zone. Cushman and Ponton's confirmation of this was based on the presence of *Virgulina* (*Virgulinella*) *gunteri* var. *curtata* Cushman and Ponton.

On the basis of Mollusca the Permenter's Farm beds might be placed in the *Ecphora* zone as they seem to be definitely younger than the *Arca* zone and have a slight preponderance of *Ecphora* zone forms over *Arca* zone forms. A total of twenty-three described species have been found in these beds. In the following list those forms that are followed by the letter C occur also in the *Cancellaria* zone; by E, in the *Ecphora* zone at one or more of the following localities, 26, 27, 28, 29, 30, 31; and by A, in the *Arca* zone at one or more of the following localities, 12, 13, 14, 15, 16, 17, 18, 24, 32. Forms not followed by a letter are confined to the Permenter's Farm beds.

MOLLUSKS FROM PERMENTER'S FARM, LOCALITY 25

Leda polychoa defuniak Gardner A, S
Arca (*Anadara*) *idonea alumensis* Mansfield E
Arca (*Anadara*) *aresta* Dall E
Ostrea disparalis Conrad E, C
Chalmys (*Plagioctenium*) *choctawhatcheensis* Mansfield A
Astarte (*Ashtarotha*) *vaughani* Mansfield A
Crassatellites (*Scambula*) *alaquaensis* Mansfield
Echinochamma arcinella (Linnaeus) C, E, A
Phacoides (*Lucinisca*) *cribrarius* (Say) E, C
Phacoides (*Lucinoma*) *contractus* (Say) E
Phacoides (*Parvilucina*) *crenulatus* (Conrad) A, E, C
Phacoides (*Parvilucina*) *multilineatus* (Toumey and Holmes) A, C
Diplodonta (*Sphaerella*) *subvexa* (Conrad) A, E
Venus campechiensis alaquaensis Mansfield
Corbula (*Corbula*) *waltonensis rubisiana* Mansfield A, E, C
Corbula (*Caryocorbula*) *nucleata* Dall A, E
Corbula (*Caryocorbula*) *barrattiana leonensis* Mansfield E, C
Panope goldfussi (*Wagner*) A, E
Turritella subannulata jacksonensis Mansfield E
Turritella cookei permenteri Mansfield
Crucibulum auriculum var. ?
Dentalium attenuatum (Say) C, E, A
Cadulus blountense Mansfield A

As may be seen from this list, only four species are confined to *Arca* zone and older beds, whereas seven species have been found only in beds as young as, or younger than, the *Ecphora* zone.

[12] W. C. Mansfield, *op. cit.*, p. 22.

[13] J. A. Cushman and G. M. Ponton, *op. cit.*, p. 15.

The foraminiferal fauna of the type locality of the Permenter's Farm beds was listed by Cushman and Ponton.[14] The microfauna of locality 19 is so like that of the type locality that the writer has considered the two localities together in the following discussion.

LIST OF MICROFAUNA OF LOCALITY 19

Foraminifera

Textularia "articulata" d'Orbigny
Textularia mayori Cushman?
Robulus americanus (Cushman)
Robulus americanus var. *spinosus* (Cushman)
Robulus iotus (Cushman)
Robulus vaughani (Cushman)
Saracenaria acutauricularis (Fichtel and Moll)
Dentalina communis d'Orbigny
Nonion grateloupi (d'Orbigny)
Nonion pizarrensis Berry
Nonion glabrellum Cushman
Nonionella auris (d'Orbigny)
Elphidium poeyanum (d'Orbigny)
Buliminella elegantissima (d'Orbigny)
Bulimina gracilis var.
Bolivina marginata Cushman
Bolivina marginata var. *multicostata* Cushman
Bolivina paula Cushman and Cahill
Uvigerina perigrina Cushman
Valvulineria floridana Cushman
Eponides mansfieldi Cushman
Rotalia beccarii var. *parkinsoniana* (d'Orbigny)
Cassidulina crassa d'Orbigny
Globigerina sp.
Orbulina universa d'Orbigny
Globorotalia menardii (d'Orbigny)
Cibicides concentricus (Cushman)

Ostracodes

Anomocytheridea floridana (Howe and Hough)
Cytheridea (*Leptocytheridea*) *choctawhatcheensis* Howe and Stephenson
Cytheromorpha warneri Howe and Spurgeon
Cythereis exanthamata var. *gomillionensis* Howe and Ellis
Cythereis gunteri Howe and Chambers
Cythereis producta (Ulrich and Bassler)
Cythereis rugipunctata (Ulrich and Bassler)
Cythereis cornuta var. *americana* Ulrich and Bassler
Cytheretta burnsi (Ulrich and Bassler)
Navecythere sp.

Consideration of this list, plus Cushman's list for the type Permenter's Farm beds, discloses that these beds contain six species that have not been found elsewhere in Florida above the middle Miocene. These species are *Sarecenaria acutauricularis* (Fichtel and Moll), *Dentalina consorbina* var. *emaciata* Reuss, *Buliminella curta* Cushman,

[14] J. A. Cushman and G. M. Ponton, *op. cit.*, check list.

Valvulineria floridana Cushman, *Anomocytheridea floridana* (Howe and Hough), and *Cytheretta burnsii* (Ulrich and Bassler). In addition, the following forms are found only rarely in the upper Miocene but are common in the middle Miocene.

Robulus iotus (Cushman)
Robulus vaughani (Cushman)
Robulus americanus (Cushman)
Robulus americanus var. *spinosus* (Cushman)
Bolivina marginata var. *multicostata* Cushman
Bolivina floridana Cushman
Pulvinulinella pontoni Cushman
Nonion pizarrensis Berry
Textularia "articulata" d'Orbigny

The only microfossil that can be regarded as distinctively upper Miocene found in these beds is *Virgulina* (*Virgulinella*) *gunteri* var. *curtata* Cushman and Ponton which was reported from the type locality by Cushman and Ponton.

The Permenter's Farm beds are assigned by the writer to the uppermost part of the middle Miocene. Their contained fauna represents a transition between the faunas of the upper and middle Miocene. These beds lie stratigraphically above the *Arca* zone, apparently in conformable contact with that unit, although the contact has not yet been found. About 80 feet of the Permenter's Farm beds were penetrated in the Niceville well so that the unit is at least that thick. The beds are assigned to the middle Miocene rather than the upper because the close affinity of the microfauna with the *Arca* zone fauna outweighs the slender affinity of the macrofauna with the *Ecphora* zone fauna. The Permenter's Farm beds are a stratigraphic unit of equal rank with the *Arca* zone. Faunally the lower limit of this unit coincides with the first appearance of *Plectofrondicularia floridana* Cushman and *Siphogenerina lamellata* Cushman, the upper limit coincides with first occurrence of *Bolivina marginata* var. *multicostata* Cushman and *Valvulineria floridana* Cushman.

The writer considers the lower bed at the Spence farm, locality 9, to be somewhat younger than the *Cardium* beds of the Shoal River formation, with which bed it was placed by Cushman and Ponton[15] and it has been treated as a separate unit in the cross section (Fig. 2), in Figure 3, and in the chart showing the ranges of certain fossils (Fig. 4). However, it is not thought advisable to set it up as a formal unit on the basis of the present knowledge of its fauna and stratigraphy.

[15] J. A. Cushman and G. M. Ponton, *op. cit.*, pp. 9–12.

The "middle" zone of the Shoal River[16] of Cushman and Ponton[17] was redefined as the *Bigenerina floridana* assemblage by Howe and McGuirt.[18] Since the "*Bigenerina floridana* assemblage" was described from Louisiana, and since the validity of the middle Shoal River designation used by Cushman for beds containing *Bigenerina floridana* Cushman and Ponton is problematical, at least in the sense used by Cushman and Ponton, the writer wishes to propose the term Whites Creek beds to designate a member of the Shoal River formation either older than, or in part equivalent to, the typical Shoal River as exposed at Shell Bluff on Shoal River. The type locality of the Whites Creek beds is locality 7 in a small gully about 200 feet south of the road from Knoxhill to Eucheeana on the east bank of Whites Creek, in Walton County, Florida. The section exposed at the type locality is as follows.

TYPE SECTION OF WHITES CREEK BEDS

	Thickness in Feet
5. Brown sand with some casts of mollusks	2
4. Lense of compact gray shell marl containing abundant *Chione cymaina* and *Conus waltonensis anodosus*. *Glycimeris waltonensis* is comparatively rare in this lense which is exposed upstream from 5	0–2
3. Below and in part equivalent to 4 is a bed of brown and yellow sand with abundant *Chione ceramota*, *Glycimeris waltonensis*, and *Crassatellites densus*	4–5
2. Gray shell marl in places indurated to form hard lumps. Fewer mollusks than the overlying beds but contains an excellent microfauna	2
1. Blue shell marl, the unweathered equivalent of the above. Penetrated by a short bore hole. Contains a good microfauna	2

The writer has found a total fauna of 293 species of fossils at this outcrop. The following list comprises only the described species.

LIST OF FAUNA OF TYPE WHITES CREEK LOCALITY 7

Textularia "articulata" d'Orbigny
Bigenerina floridana Cushman and Ponton
Robulus americanus (Cushman)
Robulus americanus var. *spinosus* (Cushman)
Robulus iotus (Cushman)
Robulus vaughani (Cushman)
Sarcenaria acutauricularis (Fichtel and Moll)
Dentalina communis d'Orbigny
Lagena clavata d'Orbigny
Lagena hexagona (Williamson)
Lagena substriata Williamson
Guttulina caudata d'Orbigny
Guttulina lactea (Walker and Jacob)
Guttulina lactea var. *earlandi* Cushman and Ozawa

[16] Quotes are the writer's.

[17] J. A. Cushman and G. M. Ponton, *op. cit.*, check list.

[18] H. V. Howe and J. H. McGuirt, "Salt Domes of Iberville and Ascension Parishes," *Louisiana Geol. Survey Bull. 13* (1938), pp. 109–10.

Globulina gibba d'Orbigny
Globulina inaequalis Reuss
Polymorphina cf. *P. advena* Cushman
Nonion grateloupi (d'Orbigny)
Nonion pizarrensis Berry
Nonion glabrellum Cushman
Nonion washingtonensis Stephenson (MS)
Nonionella auris (d'Orbigny)
Elphidium poeyanum (d'Orbigny)
Elphidium advenum (Cushman)
Elphidium chipolensis (Cushman)
Plectofrondicularia mansfieldi Cushman and Ponton
Buliminella elegantissima (d'Orbigny)
Buliminella curta Cushman
Bulimina gracilis Cushman
Bulimina gracilis var.
Virgulina cf. *V. fusiformis* Cushman
Virgulina pontoni Cushman
Virgulina (*Virgulinella*) *miocenica* Cushman and Ponton
Bolivina marginata Cushman
Bolivina marginata var. *multicostata* Cushman
Bolivina floridana Cushman
Bolivina paula Cushman and Cahill
Reusella spinulosa (Reuss)
Uvigerina peregrina (Cushman)
Angulogerina occidentalis (Cushman)
Ellipsolagena bidens Cushman
Discorbis floridana Cushman
Lamarkina atlantica Cushman
Valvulineria floridana Cushman
Eponides antillarum (d'Orbigny)
Rotalia beccarii var. *parkinsonia* (d'Orbigny)
Cancris sagra (d'Orbigny)
Amphistegina cf. *A. lessoni* d'Orbigny
Cassidulina crassa d'Orbigny
Cassidulina laevigata var. *carinata* Cushman
Cassidulinoides braydi Cushman
Orbulina universa (d'Orbigny)
Cibicides concentricus (Cushman)
Cibicides lobatulus (Walker and Jacob)
Dyocibicides biserialis Cushman and Valentine
Nucula chipolana waltonia Gardner
Nucula defuniak Gardner
Leda polychoa Gardner
Leda polychoa defuniak Gardner
Yoldia soror Gardner
Arca occidentalis Philippi
Arca (*Barbatia*) (*Plagiarca*) *marylandica* Conrad
Arca (*Barbatia*) (*Acar*) *reticulata* Gmelin
Arca (*Barbatia*) (*Fossularca*) *adamsi* Dall
Arca (*Diluvarca*) (*Diluvarca*) *latidentata* (Dall)
Arca (*Diluvarca*) (*Diluvarca*) *hypomela* (Dall)
Arca (*Diluvarca*) (*Diluvarca*) *acompsa* (Dall)
Arca (*Anadara*) *gunteri* Gardner
Arca (*Anadara*) *metastrebla* Gardner
Eontia cf. *E. incile* (Say)
Glycimeris waltonensis Gardner
Glycimeris aff. *G. pectinata* Gmelin
Ostrea cf. *O. podagrina* Dall
Ostrea cf. *O. densata* (Conrad)
Ostrea cf. *O. pauciplicata* Dall
Pecten (*Pecten*) *burnsi* Dall
Pecten (*Euvola*) aff. *P. bowdenensis* Dall

Pecten (*Chlamys*) (*Lyropecten*) *acanikos* Gardner
Pecten (*Chlamys*) (*Lyropecten*) *nicholsi neotera* Gardner
Pecten (*Chlamys*) (*Nodipecten*) *condylomatus* Dall
Pecten (*Chlamys*) (*Nodipecten*) *pyx* Gardner
Pecten (*Chlamys*) (*Plagioctenium*) *nicholsi* Gardner
Pecten (*Pseudamussium*) *defuniak* Gardner
Anomia floridana Dall
Periploma discus Gardner
Pandora (*Kennerleyia*) *dodona* Dall
Astarte (*Ashtarotha*) *sima* Gardner
Astarte (*Bythiamena*) *wagneri* Dall
Crassatellites (*Scambula*) *densus* Dall
Crassatellites (*Crassinella*) *tanicus* Dall
Cardita (*Carditamera*) *defuniak* Gardner
Venericardia (*Pleuromeris*) *aposcitula* Gardner
Venericardia (*Megacardia*) *hesperide* Gardner
Pseudochama cf. *P. chipolana* (Dall)
Pseudochama (*Echinochama*) *arcinella* (Linnaeus) Ochner
Lucina janus Dall
Lucina santarosana Dall
Phacoides (*Linga*) *glenni* Dall
Phacoides (*Cardiolucina*) *parawhitfieldi* Gardner
Phacoides (*Pseudomiltha*) *paranodonta* Gardner
Phacoides (*Parvilucina*) *vaughani* Gardner
Phacoides (*Parvilucina*) *piluliformis* Dall
Phacoides (*Parvilucina*) *diktyota* Gardner
Phacoides (*Callucina*) *cala* Gardner
Alveinus micculus Gardner
Aligena lineata Dall
Cardium (*Trachycardium*) *plectopleura* Gardner
Cardium (*Cerastoderma*) *taphirum* Dall
Cardium (*Cerastoderma*) *waltonianum* Dall
Cardium (*Fragrum*) (*Trigonicardia*) *aliculum* Dall
Dosinia (*Dosinidia*) *dalli* Gardner
Transenella caryera Gardner
Gafrarium (*Gouldia*) *erosum* Dall
Macrocallista (*Paradione*) *waltonensis* Gardner
Callocardia (*Agripoma*) *sincera* Dall
Callocardia (*Agripoma*) *calceola* Gardner
Pitar (*Pitaria*) (*Hysteroconcha*) *cypta* Gardner
Chione aff. *C. chipolana* Dall
Chione (*Lirophora*) *funiakensis* Gardner
Chione (*Lirophora*) *trimeris* (?) Gardner
Chione (*Lirophora*) *ceramota* Gardner
Chione (*Lirophora*) *crossata* Gardner
Chione (*Lirophora*) *cymaina* Gardner
Chione (*Timoclea*) *grus* (Holmes)
Venus nannodes Gardner
Tellina (*Arcopagia*) (*Phyllodina*) *leptalea* Gardner
Tellina (*Moerella*) *piesa* Gardner
Semele taracodes Gardner
Semele aff. *S. stearnsii* Dall
Semele (*Seminella*) aff. *S. striulata* Dall
Spisula (*Hemimactra*) *craspedota* Gardner
Ervilia condra Gardner
Ervilia valhosierr Gardner
Ervilia planata Dall ?
Corbula waltonensis Gardner
Corbula (*Caryocorbula*) *parawhitfieldi* Gardner
Corbula (*Caryocorbula*) *seminella* Dall
Corbula (*Caryocorbula*) *cala* Gardner
Acteon textilis (Guppy)
Acteon korphys Gardner

Acteon cf. *A. hamadryados* Maury
Acteon riomaensis Maury
Acteocina incisula (Dall) var. ?
Cylichnella biplicata (H. C. Lea)
Volvula oxytata Bush
Volvula oxytata dodona Gardner
Atys (*Aliculastrum*) *obscuratus* Dall
Cylichna decapitata (Dall)
Bulla vendryesiana Guppy
Terebra (*Strioterebra*) *waltonensis tribacka* Gardner
Terebra (*Strioterebra*) *waltonensis* Gardner var.
Polystira (*Pleuroliria*) *tenagos* Gardner
Crassispira callignoides Gardner
Clavatula probenina Gardner
Clavatula aff. *C. jamaicensis* (Guppy)
Agladrillia empera Gardner
Eumetadrillia aff. *E. dodona* Gardner
Eumetadrillia rabdotacona Gardner
"*Drillia*" *microneta* Gardner
"*Drillia*" *pycnoklosta* Gardner
"*Drillia*" *waltoniana* Gardner
Kurtziella aff. *K. prionota* Gardner
Ithycythara defuniak Gardner
Conus aff. *C. alaquaensis* Mansfield
Conus waltonensis Aldrich
Conus waltonensis anodosus Gardner
Cancellaria aff. *C. defuniak* Gardner
Cancellaria druidarum Gardner
Cancellaria pinguis Gardner
Cancellaria spherotopleura Gardner
Cancellaria aff. *C. reticulata* Linnaeus
Cancellaria (*Narona*) *atraktoides* Gardner
Oliva liodes waltoniana Gardner
Oliva litterata Lamarck
Olivella eutacta Dall
Marginella (*Serrata*) *denticulatoides* Maury
Marginella (*Serrata*) *vadosa* Gardner
Marginella (*Egouena*) *lipara lepta* Gardner
Marginella (*Gibberula*) *waltoniana* Gardner
Trivia (*Trivia*) *globosa* (Sowerby)
Mitra (*Tiara*) *mitrodita* Gardner
Mitra (*Tiara*) cf. *M. desmia* Gardner
Vexilium (*Uromitra*) *triptum* Gardner
Phos aff. *P. blountanus* Mansfield
Alectrion grapta Gardner
Alectrion dystakta Gardner
Alectrion waltonensis Gardner
Alectrion waltonensis var. *deleta* Gardner
Alectrion waltonensis Gardner var.
Nassarius (*Uzita*) aff. *N. gurabensis* (Maury)
Mitrella communis laqua Mansfield
Epitonium alaquaense Mansfield
Mellanella (*Mellanella*) *makista* Gardner
Architectonica cf. *A. granulata* Lamarck
Calyptraea cf. *C. greensboroënsis* (Martin)
Fissuridea aff. *F. griscombi* (Conrad)
Natica (*Naticarius*) *canrena antinacca* Cossman
Polynices (*Lunatia*) *hemicryptus* (Gabb)
Polynices (*Lunatia*) *heros* (Say)
Polynices (*Lunatia*) *internus* (Say)
Sigaretus chipolanus Dall
Calliostoma distans (Conrad)
Otolonia sidera (Guppy)
Solariella veresimilis (Guppy)

Dentalium cadriloide Dall
Cupuladria canariensis Canu and Bassler
Discoporella umbellata (Canu and Bassler)
Mamillopora tubulosa Canu and Bassler
Cytheridea (*Haplocytheridea*) *subovata* Ulrich and Bassler
Cytheridea (*Leptocytheridea*) *waltonensis* Stephenson
Cytheromorpha warneri var. *okaloosaensis* Howe and Spurgeon
Cytheredeis agricola Howe and Hadley
Cytheredeis ashermani Ulrich and Bassler
Cytheredeis fabula Howe and Dohm
Cytheredeis ulrichi Howe and Johnson
Cythereis exanthamata (Ulrich and Bassler) var. A
Cythereis exanthamata (Ulrich and Bassler) var. B
Cythereis cornuta var. *americana* Ulrich and Bassler
Hemicythere dalli Howe and Johnson
Cytheretta karlana Howe and Pyeat
Cytheretta inaequivalvis (Ulrich and Bassler)
Paracytheridea chipolensis Howe and Stephenson
Carcharias magna (Cope)
Carcharias collata Eastman
Carcharias (*Prionodon*) *egertoni* (Agassiz)

Of the foregoing fauna excluding those forms peculiar to it, 21 per cent of the species are found also in the *Ecphora* zone (localities 26–31); 35 per cent of the species occur in the *Arca* zone (localities 12–18, 24, 32); 48 per cent of the species occur in the Type Shoal River (locality 2); 25 per cent of the species occur in the Oak Grove (locality 21); and 31 per cent in the Chipola (locality 20 and the type Chipola). By comparison on the basis of the percentage of each fauna also occurring in the Whites Creek, the following figures have been derived.

Unit	*Localities*	*Number of Species also Found in Whites Creek*	*Total Described Fauna*	*Percentage of Total Fauna*
Ecphora zone	26–31	35	235	15
Arca zone	12–18, 24, 32	59	268	22
Yoldia zone	10, 11	29	84	35
Lower bed at Spence Farm	9	36	79	45
Type Shoal River	2	81	178	45
Upper Oak Grove	22	36	67	54
Type Oak Grove	21	43	161	27
Chipola	20 and type Chipola	52	381	14

As can be seen from this tabulation the fauna of the Whites Creek beds is closely related to that of the type Shoal River and also to that of the upper Oak Grove. The stratigraphic position of the Whites Creek beds as shown in the cross section (Fig. 2) supports the conclusion that the Whites Creek beds are either equivalent to, or slightly older than, the type Shoal River.

The beds exposed under Godwin Bridge over Shoal River, locality 4, lie stratigraphically below the type Shoal River. These beds are here placed in the Shoal River following Cooke and Mossom.[19]

[19] C. W. Cooke and Stuart Mossom, *op. cit.*, p. 112.

Examination of the cross section (Fig. 2) shows that downdip all units of the Alum Bluff group from the lower beds at the Spence farm to the typical Oak Grove apparently change to a calcareous facies which bears a Chipola fauna.

Figure 3 shows the ranges of some microfossils of particular stratigraphic value in the area of southern Walton County. Some of the ranges differ in the subsurface as found in the Niceville well. This is particularly true of some of the Ostracoda. This may be partly because the Ostracoda are more fragile than Foraminifera, hence more easily destroyed in coming up the hole in cuttings.

DESCRIPTION OF SPECIES

Order OSTRACODA Latreille
Suborder PODOCODA Sars
Family CYTHERIDAE Baird
Genus HEMICYTHERE Sars

Hemicythere calhounensis Smith, n. sp.

Plate 1, fig. 7, Plate 2, fig. 11

Carapace subquadrate, stout and fat, greatest thickness mesially. Inflated ventrally with the suggestion of an ala. Dorsal and ventral margins converging posteriorly; dorsal margin very slightly convex; ventral margin somewhat sinuous but approximating straightness. Anterior end broadly rounded, produced ventrally; posterior end narrow, oblique, meeting the dorsal and ventral margins in distinct angles. Surface with a reticulum of pits, the pits being arranged linearly in curving rows. The hinge is similar to that of *Hemicythere conradi* Howe and McGuirt.

Dimensions of Holotype No. 2862, a left valve: length, .72 mm.; height, .41 mm.; thickness, .18 mm.

PLATE I

All figures ×44.5.

Type numbers refer to the Henry V. Howe type collection at Louisiana State University.

FIGS. 1, 3, 9, 10, 15, 16.—*Cytheretta okaloosaensis* Smith n. sp. FIG. 1, a right valve, juvenile Paratype No. 2856; FIG. 3, a left valve, juvenile Paratype No. 2858; FIG. 9, a left valve, juvenile Paratype No. 2864; FIG. 10, a right valve, juvenile Paratype No. 2865; FIG. 15, a left valve, Cotype No. 2870; FIG. 16, a left valve, Cotype No. 2871.

All figured specimens from locality 21.

FIGS. 2, 6, 8.—*Cytheretta dalli* Smith n. sp. FIG. 2, a right valve, juvenile Paratype No. 2857; FIG. 6, a right valve, Cotype No. 2861; FIG. 8, a left valve, Cotype No. 2863.

All figured specimens from locality 21.

FIGS. 4, 5.—*Cytheretta gardneri* Smith n. sp. FIG. 4, a right valve, Cotype No. 2859; FIG. 5, a left valve, Cotype No. 2860.

All figured specimens are from locality 21.

FIG. 7.—*Hemicythere calhounensis* Smith n. sp. FIG. 7, a left valve, Holotype No. 2862.

The figured specimen is from locality 20.

FIGS. 11, 14, 17, 18.—*Cytheretta spencerensis* Smith n. sp. FIG. 11, a right valve, juvenile Paratype No. 2866; FIG. 14, a left valve, juvenile Paratype No. 2869; FIG. 17, a left valve, Cotype No. 2872; FIG. 18, a right valve, Cotype No. 2873.

All figured specimens are from locality 10.

FIGS. 15, 16.—*Cytheretta calhounensis* Smith n. sp. FIG. 15, a left valve, Cotype No. 2867; FIG. 16, a right valve, Cotype No. 2868.

All figured specimens are from locality 20.

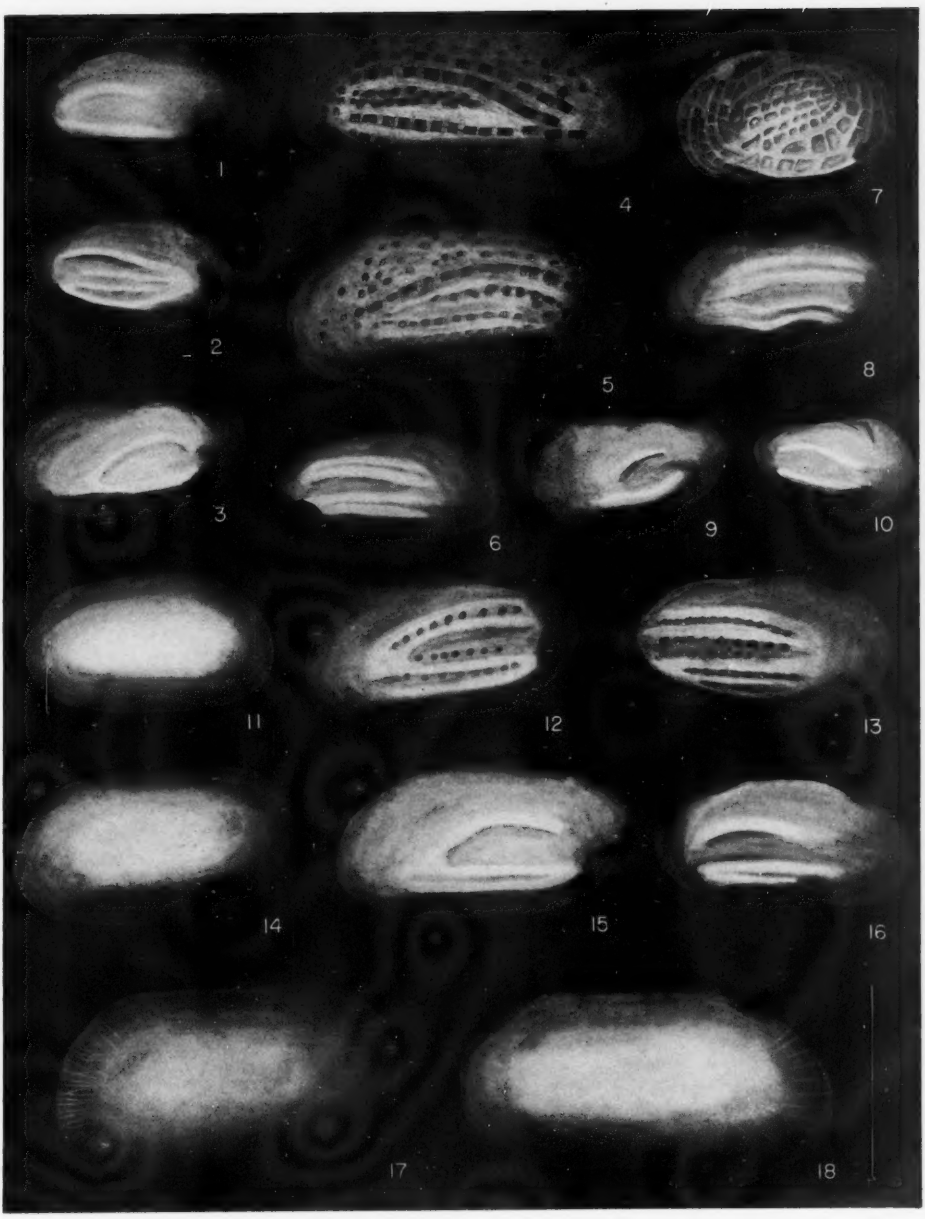


PLATE I

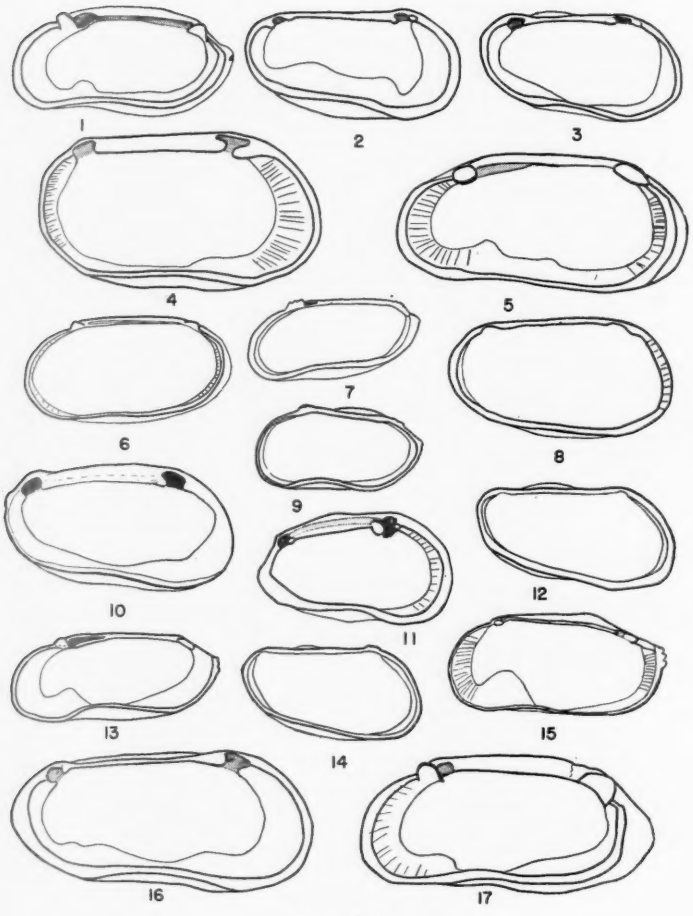


PLATE II

This species resembles *Hemicythere conradi* Howe and McGuirt, but is more produced, more coarsely reticulate, more distinctly alate, and is more inflated.

Found in the Chipola marl at the type locality on Ten Mile Creek, locality 20. Should be a good guide fossil for the Chipola.

Genus CYTHERETTA Muller

Cytheretta gardneri Smith, n. sp.

Plate 1, figs. 4, 5
Plate 2, figs. 16, 17

Carapace elongate ovate, slightly higher posteriorly. Dorsal margin nearly straight in left valve, slightly convex in right; ventral margin very slightly concave. Anterior end broadly rounded produced ventrally in right valve. Posterior end narrower, somewhat produced dorsally in the left valve, and ventrally in the right. The surface covered with a pattern of subquadrangular pits arranged in rows more or less concentric to the middle. The ridges between the rows of pits are low and rounded and do not stand out as do those of *C. karlana*. The pattern consists of three rather ill-defined rows of rounded pits dorsally; a prominent row of large quadrate pits ventral to these; centrally a short row of pits made up of two overlapping rows; ventral to the central row are four rows of subquadrate pits, two on the ventral slope and two on the lateral aspect. Anteriorly the rows of pits tend to evanesce and lose their identity. Viewed from the inside the valves are moderately deep, thick and smooth. Marginal areas rather narrow for the genus. S shape of the inner margin at the anterior end which is characteristic of the genus can be discerned only with difficulty. Radial pore canals can be faintly distinguished at the anterior end, there are not more than 15 or 20. The outer margin of the right valve is sharp and slightly keeled which, as it approaches the posterior end, turns directly up as a sharp rim separated from the periphery by a flattened area. The outer margin of the left valve likewise has a slightly raised rim which has a slightly flattened area behind it at the posterior end. The hinge of the right valve consists of a high, strong pyramidal tooth anteriorly, behind which is a deep socket. Behind this socket, the dorsal edge of the carapace forms a long wedge-shaped bar. At the posterior end of the bar there is a shallow socket open dorsally and behind that an oval, rather short, tooth. The hinge of the left valve consists of two interiorly opening sockets separated by a narrow bar whose extremities are inflated to form teeth.

PLATE II

All figures ×37.5.

Type numbers refer to the Henry V. Howe type collection.

FIGS. 1, 9, 10, 12, 14.—*Cytheretta okaloosaensis* Smith n. sp. FIG. 1, a right valve, Cotype No. 2871; FIG. 9, a right valve, juvenile Paratype No. 2856; FIG. 10, a left valve, Cotype No. 2876; FIG. 12, a left valve, juvenile Paratype No. 2858; FIG. 14, a left valve, juvenile Paratype No. 2864.

All figured specimens from locality 21.

FIGS. 2, 15.—*Cytheretta calhounensis* Smith n. sp. FIG. 2, a left valve, Cotype No. 2867; FIG. 15, a right valve, Cotype No. 2868.

All figured specimens from locality 20.

FIGS. 3, 7, 13.—*Cytheretta dalli* Smith n. sp. FIG. 3, a left valve, Cotype No. 2863; FIG. 7, a right valve, juvenile Paratype No. 2857; FIG. 13, a right valve, Cotype No. 2861.

All figured specimens from locality 21.

FIGS. 4, 5, 6, 8.—*Cytheretta spencerensis* Smith n. sp. FIG. 4, a left valve, Cotype No. 2872; FIG. 5, a right valve, Cotype No. 2873; FIG. 6, a right valve, juvenile Paratype No. 2866; FIG. 8, a left valve, juvenile Paratype No. 2869.

All figured specimens are from locality 10.

FIG. 11.—*Hemicythere calhounensis* Smith, n. sp. FIG. 11, a left valve, Holotype No. 2862.

Figured specimen is from locality 20.

FIGS. 16, 17.—*Cytheretta gardneri* Smith n. sp. FIG. 16, a left valve, Cotype No. 2860; FIG. 17, a right valve, Cotype No. 2859.

All figured specimens are from locality 21.

The juvenile differs from the adult in the more fragile carapace, the more numerous pits (about twelve rows) and in the hinge structure. The right valve has no marginal area and a very much reduced hingement consisting of two feeble terminal crenulate teeth. The muscle scar pattern consists of a vertical row of four scars, the two median slightly larger, anterior to which row ventrally is a single crescentic scar, and probably one or two small scars dorsally.

Dimensions of Cotype No. 2860, a left valve: length, 1.21 mm.; height, .53 mm.; thickness, .27 mm.; and Cotype No. 2859, a right valve of a different individual: length, 1.25 mm.; height, .52 mm.; thickness, .25 mm.

Named in honor of Miss Julia Gardner of the United States Geological Survey.

Type locality: Senterfiet's or Tanner's Mill, loc. 22.

Occurrence: found rarely at the type locality and some questionable juveniles at loc. 21.

This species belongs to the group of *Cytheretta karlana* Howe and Pyeatt. It differs from the latter in its larger size, greater proportionate length, and lack of prominence of the longitudinal ridges between the rows of pits.

Cytheretta dalli Smith, n. sp.

Plate 1, figs. 2, 6, 8
Plate 2, figs. 3, 7, 13

Carapace rather small for the genus, elongate, highest and thickest near the posterior end. Dorsal margin nearly straight, slightly convex. Ventral margin slightly concave. Anterior end broadly rounded, produced ventrally. The posterior end subacute, and faintly denticulate with the apex somewhat dorsal to the middle. Valves ornamented with two pairs of sinuous ridges diverging posteriorly. Viewed from the inside the valves are moderately deep, very thick and comparatively smooth. The marginal areas are rather wide but the inner margin is poorly defined because of a tendency to coalesce with the inside of the carapace. There is a suggestion of the S shape characteristic of the genus in the anterior ventral part of the inner margin. In the right valve the ridge-like outer margin is separated from the periphery by a broad shelf posteriorly (not shown in the drawing which was made with the valve somewhat tilted). The hinge of the right valve consists of a sharp and rather heavy anterior tooth followed by a moderately deep socket which leads to a short evanescing groove. The dorsal margin forms a bar-like ridge dorsal to this groove. Posteriorly there is a sharp elongate ridge-like tooth at the cardinal dorsal angle. Left valve with two deep sockets opening interiorly which are separated by a bar formed by the dorsal margin, before and behind these sockets the edges of the dorsal margin are expanded to make tooth-like projections. The shell material is so dense as to make radial pore canals invisible. A juvenile paratype differs mainly in its smaller size, lighter carapace, extreme narrowness of the inner margin and reduced dentition which consists, in the right valve, of terminal crenulate teeth separated by a narrow bar.

Dimensions of Cotype No. 2861, a right valve: length, .86 mm.; height, .39 mm.; Cotype No. 2863, a left valve of another individual; length, .83 mm.; height, .43 mm.; juvenile Paratype No. 2857, a right valve: length, .72 mm.; height, .34 mm.

This species is described from the type Oak Grove, locality 21, where it is common. A form that may be the same species occurs at locality 20 in the Chipola.

Cytheretta spencerensis Smith, n. sp.

Plate 1, figs. 11, 14, 17, 18
Plate 2, figs. 4, 5, 6, 8

Carapace elongate ovate, subcylindrical, the dorsal margin straight, the ventral margin gently curved and roughly parallel to the dorsal. Anterior and posterior ends smoothly rounded. Exterior of carapace smooth. Radial pore canals faintly visible at both anterior and posterior ends. Viewed from the inside the valves are moderately deep, with a broad marginal area. In the right valve the inner margin of the anterior end is somewhat sinuous approximating the S shape characterizing the genus. In the left valve this sinuosity is much less pronounced. Radial pore canals thickly clustered at both anterior and posterior ends. The outer margin of the right valve is sharp and slightly keeled toward the middle of the ventral side where it recurves dorsally forming an inward projecting flange. When it approaches the posterior end, this outer margin turns sharply up as a sharp rim with a flattened area posterior to it. The hinge of the right valve consists of a high pyramidal tooth anteriorly behind which is a shallow

socket leading to a groove extending to the base of the posterior rounded tooth. Dorsally the groove is bounded by the bar-like dorsal margin. The hinge of the left valve consists of deep sockets at each end of the dorsal margin flanked before and behind by tooth-like lobes of the dorsal margins. Between the two sockets the dorsal margin is constricted to a bar-like ridge.

Juvenile paratypes are similar to the adults in outline but taper somewhat posteriorly. Radial pore canals while visible are less than a third the length of those of the adults. Interiorly the juveniles lack the wide marginal area and heavy hingement of the adults. In the left valve the hinge consists of two slight indentations in the slightly thickened dorsal margin. In the right valve the hinge consists of two terminal, slightly crenulate teeth separated by a shallow groove.

Dimensions of Cotype No. 2873, a right valve: length, 1.20 mm.; height, .58 mm.; Cotype No. 2872, a left valve of a different individual: length, 1.15 mm.; height, .63 mm.; juvenile Paratype No. 2866, a right valve: length, .81 mm.; height, .44 mm.; juvenile Paratype No. 2869, a left valve: length, .93 mm.; height, .53 mm.

This species is described from locality 10; it is also found at localities 8, 9, and 11. In the outcrop this species appears to be a good marker for the *Yoldia* zone and the upper part of the Shoal River.

Cytheretta calhounensis Smith, n. sp.

Plate 1, figs. 12, 13
Plate 2, figs. 2, 15

Carapace elongate, ovate, highest near the posterior end. Dorsal margin slightly convex, vertral margin slightly concave. Anterior end broadly rounded, slightly produced ventrally. Posterior end subacute terminating somewhat dorsal to the middle. Posterior end of the right valve faintly denticulate. The surface ornamented with four or five longitudinal ribs between which lie rows of rounded pits. Viewed from the inside the valves are thick, only moderately deep, translucent, with the exterior pits clearly visible. The marginal area is broad and anteriorly and ventrally curves in the characteristic S form of the genus. In the right valve the outer margin is almost coincident with the periphery posteriorly, differing in this respect from many other species of the genus where characteristically the rim-like inner margin is separated from the periphery at the posterior end. The hinge of the right valve consists of a large anterior oval tooth behind which is the suggestion of a socket leading to a faint groove which is situated ventral to the bar-like dorsal margin. Posteriorly there is an oblong tooth somewhat smaller than the anterior one. The hinge of the left valve consists of anterior and posterior sockets flanked by tooth-like projections of the dorsal margin and connected by a narrow, bar-like ridge. The radial pore canals are long, but not very numerous anteriorly, posteriorly they are more numerous but shorter.

Dimensions of Cotype No. 2868, a right valve: length .84 mm.; height, .41 mm.; Cotype No. 2867, a left valve of another individual: length, .84 mm.; height, .44 mm.

This species is described from locality 20, so far as is known it is confined to the Chipola formation.

Cytheretta okaloosaensis Smith, n. sp.

Plate 1, figs. 1, 3, 9, 10, 15, 16
Plate 2, figs. 1, 7, 9, 10, 11, 14

Carapace small for the genus, oblong ovate. Dorsal margin slightly convex, ventral margin nearly straight in the left valve, rather markedly concave in the right. Anterior end broadly rounded, somewhat produced ventrally, posterior end subacute with the apex dorsal to the middle. The surface is ornamented with a pair of arcuate longitudinal ribs becoming more distant posteriorly. The ventral of these ribs tends to become bipartite posteriorly in the adult. There is a suggestion of longitudinal ribbing on the ventral slope. On the inside the valves are smooth and only moderately deep. The marginal area is broad but ill defined. The inner margin shows an S-shaped outline anteriorly and ventrally. The ridge-like outer margin of the right valve is somewhat separated from the periphery posteriorly and posteriorly ventrally. The hinge is rather heavy consisting in the right valve of a very heavy, triangular anterior tooth posterior to which is a rather large but ill defined socket which leads into a shallow groove situated ventral to the bar formed by the dorsal margin. At the posterior extremity of the bar and pit there is a heavy oblong tooth situated at the cardinal angle. The hinge of the left valve consists of two deep sockets opening interiorly separated by a rather narrow bar formed by the dorsal margin. The ends of this bar are produced in tooth-

like projections, the heavier of which is the anterior. The dorsal margin at the anterior dorsal angle is likewise produced forming a tooth-like process. Because of the density of the shell material radial pore canals are not visible.

Juveniles resemble the adult but have no suggestion of ribbing on the ventral slope, the main ventral rib is without suggestion of bifurcation, the marginal area is very narrow, and the dentition is reduced to very light, terminal, elongate, crenulate teeth in the right valve and a suggestion of corresponding sockets in the left.

Dimensions of Cotype No. 2870, a right valve: length, .95 mm.; height, .45 mm.; Cotype No. 2871, a left valve of another individual: length, .87 mm.; height, .46 mm.; juvenile Paratype No. 2865, a right valve: length, .59 mm.; height, .26 mm.; juvenile Paratype No. 2856, a right valve: length, .68 mm.; height, .35 mm.; juvenile Paratype No. 2864, a left valve: length, .79 mm.; height, .42 mm.; juvenile Paratype No. 2858, a left valve: length, .72 mm.; height, .39 mm.

Described from locality 21, also found at locality 20 and questionably at localities 22 and 4.

This species is closely allied to *Cytheretta inaequivalvis* (Ulrich and Bassler) found in the Shoal River, but is smaller and lacks the conspicuous radial pore canals of the latter. It resembles an undescribed species found in the *Cancellaria* zone of the Choctawhatchee in the ribbing of the ventral slope. *Cytheretta okaloosaensis* differs from the *Cancellaria* zone form in the simplicity of the dorsal rib. *Cytheretta inaequivalvis* differs in having both dorsal and ventral ribs single in the adult. *Cytheretta dalli* differs from *Cytheretta okaloosaensis* in that both ventral and dorsal ribs are paired.

LIST OF LOCALITIES MENTIONED IN THIS ARTICLE

Samples collected from these localities by the writer in August or December, 1939, except as otherwise noted.

Locality 1. Old Summerville millrace. This locality is in Holmes County, about 1 mile east of Argyle, Walton County, Florida. The fauna is listed by Miss Gardner[20] under U.S.G.S. loc. 3748. It is in the NE. ¼ of Sec. 34, T. 3 N., R. 18 W., Holmes County, Florida. Age: Shoal River, perhaps a little younger than the type. Elevation, 145 feet.

Locality 2. Shell Bluff on Shoal River, the type locality of the Shoal River formaton, and the same as U.S.G.S. loc. 3742 and *Florida Bull. 9*,[21] sample 31. The best exposure is in a ravine on the McClellan farm in the SE. ¼, NW. ¼ of Sec. 4, T. 3 N., R. 21 W., Walton County, Florida. The thin shell bed from which the sample was taken lies at an elevation of 137 feet.

Locality 3. Dave Adams Mill Creek, Sec. 2, T. 3 N., R. 21 W., Walton County, Florida. This is the same as U.S.G.S. loc. 3732. Age: Shoal River, typical. Elevation, 150 feet.

Locality 4. Beds cropping out below Godwin Bridge about ½ mile below Shell Bluff on Shoal River, Walton County, Florida. The locality is situated under an iron bridge in the approximate center of Sec. 4, T. 3 N., R. 21 W. Age: Shoal River, slightly older than the type. Elevation, 90 feet.

Locality 5. Beds cropping out in a small ravine cutting into Shell Bluff about half way between localities 2 and 4. Age: Shoal River, typical. Elevation, 115 feet.

Locality 6. Lowest bed exposed on Folks Creek, on Armstrong's farm in the SE ¼, NE. ¼ of Sec. 22, T. 2 N., R. 18 W., Walton County, Florida. Age: Shoal River, Whites Creek. Elevation, about 80 feet.

Locality 7. Type locality of the Whites Creek member of the Shoal River formation. The locality is situated in a small gully on the east bank of Whites Creek about 200 feet south of the road from Eucheeana to Knoxhill in the SE. ¼, NE. ¼ of Sec. 23, T. 2 N., R. 18 W., Walton County, Florida. This is U.S.G.S. loc. 10603, *Florida Bull. 9*, sample 28. Elevation, 75 feet.

Locality 8. From bluff about 300 yards south of a house belonging to R. A. Henderson, in the NE. ¼ of Sec. 6, T. 2 N., R. 19 W., Age: *Cardium* beds of the Shoal River. Elevation, about 100 feet.

Locality 9. Lowest bed exposed at a small dripping spring on the Chester Spence farm in the NE. ¼, NE. ¼ of Sec. 17, T. 2 N., R. 19 W., Walton County, Florida. Age: Uppermost part of the Shoal River formation. This is *Florida Bull.* 9, sample 4 B. Elevation at top of bed, 125 feet.

[20] J. A. Gardner, *op. cit.*

[21] J. A. Cushman and G. M. Ponton, *op. cit.*

Locality 10. Upper 10 feet of material exposed at a dripping spring on the Spence farm (see locality 9). This is *Florida Bull. 9*, sample 4 A. Age: *Yoldia* zone of the Choctawhatchee. Elevation at base of bed, 125 feet.

Locality 11. Type locality of the *Yoldia* zone. Frazier's old farm (formerly the Spencer farm) in the SE. ¼ of Sec. 18, T. 2 N., R. 19 W., Walton County, Florida. This is U.S.G.S. loc. 12060. *Florida Bull. 9*, sample 4 B. Age: *Yoldia* zone of the Choctawhatchee formation. Elevation, 90 feet.

Locality 12. Bell's farm in the NE. ¼ of Sec. 29, T. 2 N., R. 19 W., Walton County, Florida. This is the same as U.S.G.S. loc. 12044, *Florida Bull. 9*, sample 11. The exposure here is at the head of a small branch flowing into Sconiers Mill Creek. Age: *Arca* zone of the Choctawhatchee. Elevation, 130 feet.

Locality 13. Sample from beds cropping out in the bed of Blounts Creek along ¼-mile stretch extending downstream from an old mill in the SE. ¼ of Sec. 26, T. 2 N., R. 19 W., Walton County, Florida. This is U.S.G.S. loc. 12047. Age: *Arca* zone of the Choctawhatchee. Elevation, 46 feet at base of the outcrop.

Locality 14. At a small spring head in E. Gomillion's field near Red Bay in Walton County, Florida. This is U.S.G.S. loc. 1/673 and 1/950 and *Florida Bull. 9*, sample 41. Age: *Arca* zone of the Choctawhatchee.

Locality 15. John Anderson's farm ¾ mile east of Red Bay, Walton County. This locality is regarded as the type locality of the *Arca* zone of the Choctawhatchee formation, and also of the Choctawhatchee formation. This is U.S.G.S. loc. 1/948, *Florida Bull. 9*, sample 40. Collected by H. V. Howe and M. C. Israelsky in the summer of 1934.

Locality 16. Jim Kennedy Branch, one mile east of Red Bay, Walton County. This is the same as U.S.G.S. loc. 1/671, 1/947, and *Florida Bull. 9*, sample 15. Age: *Arca* zone of the Choctawhatchee.

Locality 17. From bluff on left bank of Blount Creek just above the entrance to Alaqua Creek. Approximately $\frac{1}{16}$ mile below bridge on the County road. SW. ¼, NE. ¼ of Sec. 32, T. 2 N., R. 19 W. Age: *Arca* zone of the Choctawhatchee. Elevation, 38 feet.

Locality 18. On Alice Creek, a tributary of Alaqua Creek near the NE. corner of the SE. ¼ of Sec. 8, T. 1 N., R. 19 W., Walton County, Florida, and about 1 mile northeast of the locality on Permenter's old farm. Same as U.S.G.S. loc. 13527, and *Florida Bull. 9*, sample 30. Age: *Arca* zone of the Choctawhatchee. Elevation, 75 feet at top of outcrop.

Locality 19. In a road-cut in the SW. ¼, NW. ¼ of Sec. 16, T. 1 N., R. 19 W., Walton County, Florida. Age: Permenter's Farm beds of the Choctawhatchee. Elevation, 75 feet.

Locality 20. Near water level on Tenmile Creek, from bridge to ½ mile below bridge on the Marianna-Clarksville road, 22 miles south of Marianna, Calhoun County. *Florida Bull. 9*, sample 10. Age: Chipola formation.

Locality 21. At old saw-mill near Oak Grove on right bank of Yellow River about 100 yards below bridge on Laurel Hill-Oak Grove road, Okaloosa County, Florida. Same as U.S.G.S. loc. 7054 and *Florida Bull. 9*, sample 26. Age: Type of Oak Grove sand. Collected by H. V. Howe and M. C. Israelsky.

Locality 22. Senterfiet's or Tanner's Mill (abandoned), 4 miles southwest of Laurel Hill, Okaloosa County, Florida. Same as U.S.G.S. loc. 10659 and *Florida Bull. 9*, sample 29. Age: Upper Oak Grove. Collected by H. V. Howe and M. C. Israelsky.

Locality 23. One-quarter mile west of Alaqua School or Pleasant Ridge Church, in small gorge cut by the run of a dripping spring on the Stafford farm in Sec. 6, T. 2 N., R. 19 W., Walton County, Florida. Same as U.S.G.S. loc. 9959 and *Florida Bull. 9*, sample 5. Age: *Cardium* beds of the Shoal River. Collected by H. N. Fisk.

Locality 24. Outcrop in old road bed at W. E. Collin's farm, SE. ¼, NE. ¼ of Sec. 15, T. 2 N., R. 15 W., Washington County, Florida. Age: *Arca* zone of the Choctawhatchee.

Locality 25. Permenter's old farm in Sec. 17, T. 1 N., R. 19 W., Walton County, Florida. The exposure of shell marl occurs in a road-cut leading to an abandoned bridge on the east bank of Alaqua Creek. Same as U.S.G.S. loc. 12048 and *Florida Bull. 9*, sample 21. Age: Type locality of the Permenter's Farm member of the Choctawhatchee.

Locality 26. Lowest shell bed lying directly on top of the Hathorn formation at Jackson Bluff, left bank of Ocklocknee River just above highway bridge, Leon County, Florida. Same as *Florida Bull. 9*, sample 37. Age: *Ecphora* zone of the Choctawhatchee.

Locality 27. On Harvey's Creek at abandoned mill about ½ mile above Florida Road No. 19, in Sec. 8, T. 1 S., R. 3 W., Leon County, Florida. Same as U.S.G.S. loc. 1/965 and *Florida Bull. 9*, sample 38. Age: *Ecphora* zone of the Choctawhatchee.

Locality 28. Upper shell beds at Alum Bluff on the east bank of the Apalachicola River about 4 miles north of Bristol, Liberty County, Florida. Same as U.S.G.S. loc. Nos. 1/670 and 1/956 and *Florida Bull. 9*, sample 12. This is the type locality of the *Ecphora* zone. Age: *Ecphora* zone of the Choctawhatchee.

Locality 29. Cut in road leading to Watson's Landing, Liberty County, Florida, about 2 miles north of Alum Bluff and about the same distance from the Apalachicola River. Same as U.S.G.S. loc. 1/962 and *Florida Bull. 9*, sample 39, Age: *Ecphora* zone of the Choctawhatchee.

Locality 30. Dripping Spring on Fourmile Creek, ½ mile northwest of Clarksville, Calhoun County, Florida. Same as U.S.G.S. loc. 1/954 and *Florida Bull. 9*, sample 1. Age: *Ecphora* zone of the Choctawhatchee.

Locality 31. Darling Slide, an old log slide at a bluff on the east bank of the Chipola River about 2½ miles southeast of Clarksville, Florida. Same as U.S.G.S. loc. 1/960 and *Florida Bull. 9*, sample 32. Age: *Ecphora* zone of the Choctawhatchee.

Locality 32. From a small tributary to Blounts Creek in the SW. ¼ of Sec. 26, T. 2 N., R. 19 W., Walton County, Florida. This is probably the same as *Florida Bull. 9*, sample 8. Age: *Arca* zone of the Choctawhatchee. Elevation, approximately 135 feet.

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PRE-CAMBRIAN ZEOLITE-OPAL SEDIMENTS IN WICHITA MOUNTAINS, OKLAHOMA[1]

C. A. MERRITT[2] AND W. E. HAM[2]
Norman, Oklahoma

ABSTRACT

Rocks of a unique type have been recently discovered in the Wichita Mountains of southwestern Oklahoma. Composed principally of zeolites and opal, with variable amounts of dolomite and calcite, these rocks occur as four scattered outcrops in Kiowa County. They appear to be stratified and have a maximum thickness of 47 feet. The name "Tepee Creek" is given to these zeolite-opal rocks.

The Tepee Creek sediments rest with an erosional unconformity on anorthosite and contain rounded pebbles of that igneous rock. The formation, furthermore, is intruded by several small granite dikes of pre-Cambrian age. The unconformity, the zeolite-opal rocks, and the period of igneous activity represented by the granite dikes have not been previously recognized.

Evidence is presented to show that the zeolites and opal have formed by the alteration of a sediment which was essentially an anorthosite-graywacke, with some beds containing dolomite and perhaps limestone. The zeolites, chiefly natrolite, and the opal are secondary. The zeolites probably were derived diagenetically by the action of saline waters of a pre-Cambrian sea on the labradorite of the detrital anorthosite. The opal may be partly diagenetic but some of it is later, for it replaces natrolite.

INTRODUCTION AND ACKNOWLEDGMENTS

The writers have had the opportunity of studying many of the samples collected during the recent mineral survey of Oklahoma.[3] Among the specimens from the Wichita Mountains was a fine-grained, reddish, calcareous rock, containing an abundance of zeolites and opal. The exceptional character of this rock led to an investigation of its occurrence and the preliminary results were published.[4] Field study has shown the zeolite-opal rock has a rather extensive outcrop in the western part of the Wichita Mountains, and the writers believe this rock is a pre-Cambrian altered sediment. The name "Tepee Creek" is given to this sedimentary formation because of an excellent exposure near the junction of Tepee Creek and the North Fork of Red River.

The writers wish to express appreciation to Robert H. Dott for his valuable advice and assistance in the field studies.

GENERAL GEOLOGY OF WICHITA MOUNTAINS

The Wichita Mountains are located in southwestern Oklahoma, principally in Kiowa and Comanche counties. The mountain system

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[2] Department of geology, University of Oklahoma, Norman, Oklahoma.

[3] W.P.A. Project 65-65-538, sponsored and directed by the Oklahoma Geological Survey.

[4] C. A. Merritt and W. E. Ham, "Zeolitic Rocks in the Wichita Mountains, Oklahoma," *Proc. Oklahoma Acad. Sci.*, Vol. 19 (1939), pp. 115-17.

forms a physiographic unit of irregular peaks and low knobs with a maximum relief of about 1,000 feet. The maximum extent is approximately 65 miles northwest and southeast; the width is nowhere more than 28 miles, and it is much less in the western part. The peaks are discontinuous, being separated by flat valleys or plains.

The mountain complex consists of an igneous core upon which has been deposited a considerable thickness of lower Paleozoic sandstone, dolomite, and limestone. These sediments have since been folded, and exposed as steeply dipping hogbacks at the northeast, east, and southeast margins of the igneous core, by a late Paleozoic uplift. During Permian time the Wichitas were at least partly covered by redbeds which now crop out at the margins of the uplift and between the numerous isolated igneous peaks of the western part.

The Wichita Mountain igneous rocks are pre-Cambrian in age and are composed chiefly of granophyres and gabbro-anorthosite.[5,6] Hoffman[7] considers the age relationships of the pre-Cambrian rocks to be: Meers quartzite (oldest), gabbro-anorthosite, and granophyres and dike rocks (youngest).

Meers quartzite.—This rock, the oldest known in the Wichita Mountains, consists of subangular to rounded quartz grains 0.2–1.0 mm. in diameter. It has been intruded by gabbro and granophyre, and now occurs as isolated inclusions in those rocks.

Gabbro and anorthosite.—The exposures of basic rocks vary from small outcrops less than a square mile in extent to masses 14 miles long and as much as 4 miles wide. The color is white, gray, or black, the dark varieties being more common. Most exposures are fresh but portions near granophyric intrusions show hydrothermal alterations.

The texture of the basic rocks is medium- to coarse-grained. Lath-shaped and tabular crystals of labradorite are ordinarily visible in hand specimens, and in places a parallel arrangement of the feldspar gives the rock a schistose appearance. The schistosity probably developed during the intrusion and does not represent subsequent metamorphism.

The essential mineral is labradorite. Most of the basic rocks contain more than 80 per cent of this mineral and in some it amounts to 96 per cent. Most of these rocks are anorthosites, but with the increase of ferromagnesian minerals they grade into gabbro-anorthosite

[5] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains, *etc.*," *Oklahoma Geol. Survey Bull. 12* (1927).

[6] C. H. Taylor, "Granites of Oklahoma," *ibid.*, *Bull. 20* (1915).

[7] M. G. Hoffman, "Geology and Petrology of the Wichita Mountains," *ibid.*, *Bull. 52* (1930).

and gabbro. Diallage is commonly the principal ferromagnesian mineral, but hornblende, augite, or biotite may predominate. The minor accessories are apatite, titanite, zircon, magnetite, and locally, quartz. The magnetite, which is titaniferous, is scattered throughout the rocks as small grains, in some places amounting to 6 per cent of the rock, whereas in a few places there are local magmatic segregation deposits of titaniferous magnetite.[8]

Granophyres.—The acidic rocks of the Wichitas, formerly called granites, have recently been designated granophyres by Hoffman in his studies of the eastern part of the Wichita Mountains.[9] He subdivided the granophyres into five groups, each differing slightly in texture and time of intrusion. The textures are fine-, medium-, and coarse-grained, and some are porphyritic.

The essential minerals are quartz and alkali feldspars. The ferromagnesian constituents, ordinarily less than 8 per cent, are hornblende (rarely riebeckite) and biotite. Minor accessories are zircon, apatite, titanite, and magnetite. Some of the rocks are comparatively fresh while others have been altered: biotite and hornblende have altered to chlorite, and the feldspars to kaolin and sericite.

Hoffman concluded that the granophyres were intruded as thick sills at various depths below the surface. The coarse- and medium-grained types were believed to be hypabyssal while the fine-grained and porphyritic types were thought to be extrusive or near-surface phases of the coarser-textured ones.

Dike rocks.—Aplite, pegmatite, diabase, and quartz dikes are more or less abundant throughout the igneous area, cutting anorthosite and granophyres.

It has generally been considered that all the igneous rocks in the Wichita Mountains are differentiation products of one original magma. The writers believe they have evidence, as explained later, of a second period of igneous activity, a period separated from the first by an erosional unconformity.

Paleozoic sediments.—Exposed on the flanks of the igneous rocks are outcrops of lower Paleozoic sediments, the oldest of which is the Reagan sandstone (Upper Cambrian).[10] This sandstone, as well as a basal limestone member, contains fragments derived from the various igneous outcrops, proving that the igneous rocks are older than the

[8] C. A. Merritt, "The Iron Ores of the Wichita Mountains, Oklahoma," *Econ. Geol.*, Vol. 34 (1939), pp. 268–86.

[9] M. G. Hoffman, *op. cit.*

[10] C. E. Decker, "Progress Report on the Classification of the Timbered Hills and Arbuckle Groups, *etc.*," *Oklahoma Geol. Survey Cir. 22* (1939).

sediments. As no dikes have been found intruding the sediments, it is assumed that all the igneous activity in the Wichita Mountains is pre-Reagan and probably pre-Cambrian.

LOCATION OF TEPEE CREEK OUTCROPS

The zeolite-opal rocks (Tepee Creek formation) occur as four scattered outcrops in the interior part of the Wichita Mountains in Kiowa County (Fig. 1). It seems likely that detailed studies will show the zeolite-opal rock is more extensive in this area than is now known.

For purposes of description the outcrops may be divided into two groups, (1) the northwest outcrop exposed along the North Fork of Red River, 6 miles west of Roosevelt, and (2) the three southeast outcrops near Cold Springs.

The northwest outcrop covers an area of approximately 5 acres in the SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 6, T. 4 N., R. 18 W., and in the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 1, T. 4 N., R. 19 W. At this locality the zeolite rock rests unconformably on the south and west sides of an isolated low hill of anorthosite. A vertical section of the zeolite-opal rock, measured with a hand-level, was 47 feet. This figure may not represent the true thickness, as the exact dip is difficult to determine, although the rocks appear to be almost horizontal.

A trench about 8 feet deep and about 20 feet long has been dug in the zeolite-opal rock on the south side of the hill and on the southwest side there is an inclined tunnel, now water-filled except the upper 30 feet. Both excavations were made by a prospector many years ago.

The three southeast outcrops occur in T. 4 N., R. 17 W. The largest of these is principally in the E. $\frac{1}{2}$, SE. $\frac{1}{4}$ of Sec. 30 and SW. $\frac{1}{2}$, SW. $\frac{1}{4}$ of Sec. 29, and covers an area of approximately 80 acres. Another, about 50 acres, crops out in the N. $\frac{1}{2}$ of Sec. 32 and in the S. $\frac{1}{2}$ of Sec. 29. The smallest outcrop covers about 40 acres in the central part of SE. $\frac{1}{4}$ of Sec. 26. No determination of thickness was made at these outcrops because the base is not exposed. Each outcrop, however, appears to rise at least 20 feet above the level of the surrounding flats. These rocks were probably once a continuous outcrop but have since become separated by erosion and soil covering.

These pre-Cambrian rocks were mapped as Permian redbeds by Taff,[11] which was a natural assumption with the data available at that time. Detailed studies are necessary to delineate the outcrops of the Permian redbeds and the pre-Cambrian sediments in this region.

[11] J. A. Taff, *op. cit.*

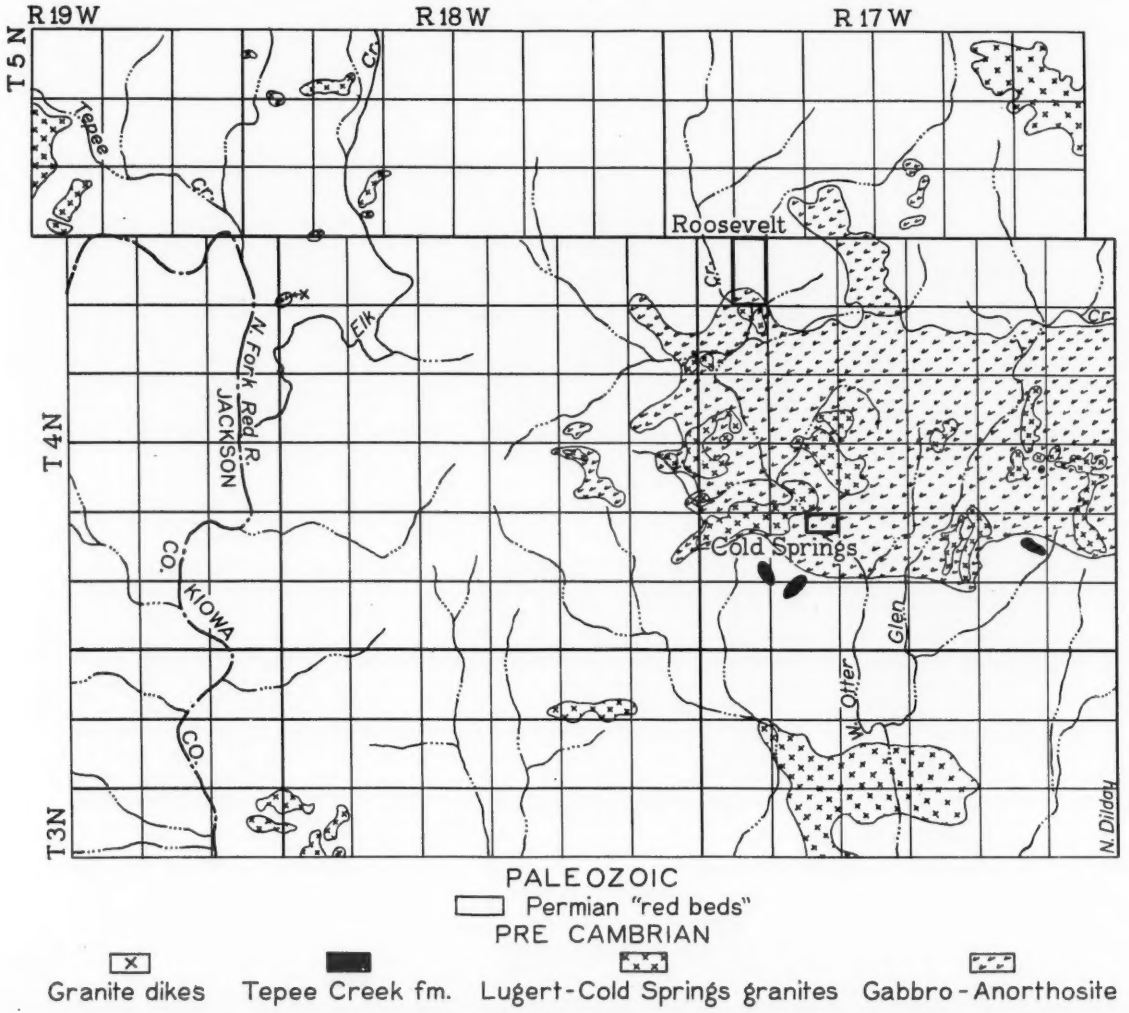
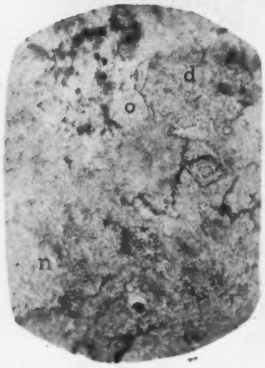


FIG. 1.—Geologic map of west-central Wichita Mountains, Oklahoma, showing location of Tepee Creek formation. Modified from C. H. Taylor, *Oklahoma Geol. Survey Bull. 20* (1915).

3

4



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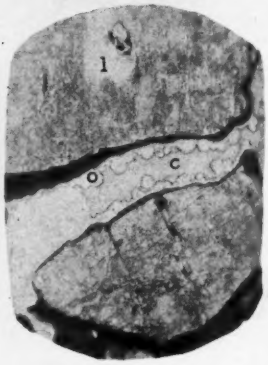

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PLATE I, Figures 2–6

GENERAL DESCRIPTION OF ZEOLITE-OPAL ROCK

The zeolite-opal rock ordinarily has a dull brick-red color, speckled with white, and commonly shows small grains of black, shiny ilmenite. It varies from this appearance to dark purplish red on one hand and to light gray on the other. Typically it is dense, compact, and tough, but in a few thin seams the rock is somewhat soft and easily crumbled. In other places, the rock is altered at the surface and is friable. At some places it has a porous crust of calcite.

The Tepee Creek sediments are composed essentially of zeolites and opal with variable amounts of calcite and dolomite. Halloysite, hematite, limonite, and detrital ilmenite and feldspar fragments make up a minor part of the rock. Locally, rounded pebbles of pink or white anorthosite, ranging in size from 0.1 inch to 3 inches, are abundant. These locally give the rock a distinct conglomeratic appearance; in the typical specimen, however, few pebbles can be seen.

A distinct layering was seen in several places. Two massive beds, each about one foot thick, were observed at the top of the trench in the northwest outcrop (Fig. 2). At the same locality a thin layer of halloysite was seen near the bottom of the inclined tunnel. Road cuts and gullies in the southeast outcrops show successive layers several inches thick.

In addition to these features there are many vug-like openings which are partly filled with euhedral calcite, analcime, or natrolite. Less commonly these cavities are crusted with opal. The northwest outcrop, but not those on the southeast, is strongly veined with calcite. All outcrops show a few stringers of opal.

FIG. 2.—Part of outcrop (Sec. 6, T. 4 N., R. 18 W.) of Tepee Creek formation, showing layers which are interpreted as sedimentary beds. Layer on which hammer rests contains 66.13 per cent zeolites, 11.59 per cent opal, and 22.28 per cent dolomite.

FIG. 3.—Photomicrograph of zeolite-rich rock from tunnel (SE. $\frac{1}{4}$ of Sec. 1, T. 4 N., R. 19 W.), showing light gray opal (*o*) replacing dark needles of natrolite (*n*). Black is hematite dust; (*c*) is calcite. ×45.

FIG. 4.—Photomicrograph of light gray zeolite-opal aggregate replacing labradorite fragments. These pieces are surrounded and cemented with iron-stained opal. Large area in center shows indistinct parallel lines which probably represent cleavage lines or twinning striations of original labradorite. ×45.

FIG. 5.—Photomicrograph of specimen from SE. $\frac{1}{4}$ of Sec. 1, T. 4 N., R. 19 W., showing indistinct radiating clusters of fibrous natrolite (*n*). Upper right field is dolomite (*d*), in which one distinct rhombohedron can be seen. A little opal (*o*) and some black hematite dust are present. ×45.

FIG. 6.—Photomicrograph of specimen of typical Tepee Creek rock from Sec. 26, T. 4 N., R. 17 W. Labradorite (*l*) is partly replaced by fine-grained aggregate of calcite, opal, and natrolite. Plagioclase grains are surrounded by iron-stained opal (*o*), and calcite (*c*). Each of the larger pieces is a partially altered labradorite fragment which shows albite twinning in optical continuity. ×45.

Scale for all photomicrographs: $1\frac{1}{8}$ inches = 1 millimeter.

MINERALOGICAL CHARACTER

Approximately half of the rock is composed of zeolites, although the zeolite content is variable, in some places within short distances along the outcrop. A few portions of the rock, especially some of the veinlets and crusts, are nearly completely zeolitized, while elsewhere zeolites may make up no more than 25 per cent of the rock. These minerals are microscopic in size.

Natrolite is the most abundant zeolite; it ordinarily occurs as small felted needles and fibers scattered throughout the rock, commonly replacing labradorite. It also occurs in cavities and partly filled veins as tufts of radiating needles and as globular aggregates of compact divergent needles with a concentric structure (Figs. 3, 4, 5 and 6).

Analcime, which is rather minor in amount, occurs in cavities, invariably in colorless, glassy, euhedral trapezohedrons up to 0.25 mm. in diameter.

Calcite occurs as anhedral crystals scattered throughout the rock and as euhedral, acute rhombohedra in cavities (Figs. 3, 4, and 6). There are also veins and stringers of calcite cutting the zeolite-opal rock. Some of the calcite is an alteration product of labradorite.

Dolomite is present, ordinarily in small amounts (Fig. 5), but in one bed it forms a large part of the rock, while in others it is absent.

The southeast outcrops ordinarily contain a small quantity of carbonate; two analyses gave 1.77 and 9.74 per cent calcium carbonate. The carbonates are more abundant in the northwest outcrop. Detailed analyses from the latter area, taken at various stratigraphic intervals, showed the carbonate content to be variable in amount as well as in the ratio of calcite to dolomite. The average of seven carbonate analyses was 32.95 per cent: the extremes are 64.31 and 14.52 per cent. Most of the analyses showed a mixture of dolomite and calcite, but one is pure dolomite and two are nearly pure calcite.

Opal is ubiquitous in occurrence but is variable in amount. The northwest outcrop, which is high in carbonate, is correspondingly low in opal. Twelve per cent is the average amount in the rocks of this area, but one analysis showed 24.28 per cent. The southeast outcrops, however, are much more opalized, one typical analysis showing 46.20 per cent. The opal is extremely fine-grained and is scattered throughout the rock, acting as a cement. Small veinlets of opal commonly are present in the outcrops.

Petrographically the opal is of two types: (1) a dull, iron-stained mass consisting of minute aggregates, and (2) a clear, glassy type which has replaced natrolite (Fig. 3) and labradorite. Both varieties show weak anisotropism. The opal has a variable water content, in-

dicated by its index of refraction which ranges from 1.43 to slightly less than 1.45 in different specimens. The opal has a hardness of 6.0 and is soluble in *KOH*.

The quantitative determination of opal in the rock was made by heating the powdered sample in dilute *HCl* for a few minutes and then decanting. This procedure, when carried out three or four times, effectively removes the jelly formed by the action of the acid on the zeolites. The carbonates also are dissolved. Examination of the insoluble material proved it to be essentially opal, with minor amounts of halloysite and detrital ilmenite and plagioclase.

Although this opal is essentially hydrous silica, it contains notable quantities of alumina, ferric oxide, lime, and magnesia, as can be seen in Table I. This composition, however, is not exceptional for minerals of colloidal origin, which usually contain impurities. For comparison an analysis of a siliceous sinter from Splendid Geyser, Yellowstone Park, Wyoming (analysis II) is given.

TABLE I

	I*	II†
SiO_2	79.07	81.95
Al_2O_3	4.74	6.49
Fe_2O_3	1.18	—
FeO	—	tr.
MnO_2	—	—
CaO	2.22	0.56
MgO	2.48	0.15
K_2O	tr.	0.65
Na_2O	tr.	2.56
SO_3	—	0.16
Cl	—	tr.
H_2O	10.38	7.50
Total	100.07	100.02

* Analysis of opal (acid insoluble fraction) of sample approximately 20 feet above base, Sec. 6, T. 4 N., R. 18 W. Analysis by R. G. Mihram, chemist, Oklahoma Geological Survey.

† W. H. Weed, Formation of travertine and siliceous sinter by the vegetation of hot springs, *U. S. Geol. Survey 9th Ann. Rept.* (1889), p. 670.

Halloysite is found only near the bottom of the inclined tunnel in Sec. 1, T. 4 N., R. 19 W. It has the form of a distinct layer about 6–12 inches thick, and dips gently eastward. It is pink to white and has a waxy feel and luster. It is insoluble in acids, contains aluminum, and has 21.23 per cent water; no magnesium is present. The index of refraction is between 1.50 and 1.51 and it has a weak, anomalous double refraction. These data indicate the mineral is halloysite.

Iron oxides are present in small quantities and give the rock a reddish color. Chemical analyses of the zeolite-opal rock show Fe_2O_3 varying from 2.96 to 1.74 per cent. The iron is present largely as the mineral hematite and, to a lesser extent, limonite. A little iron is an adsorbed impurity in opal.

Other minerals present in the zeolite rock are those which have been mechanically derived from the erosion of anorthosite. Labradorite, in the form of pebbles and as small lath-shaped crystals, ilmenite, and flakes of decomposed biotite occur sporadically.

Paragenesis.—From a study of replacement and veins the paragenesis of the secondary minerals seems to be as follows: (1) natrolite (earliest), (2) analcime, and (3) vein calcite. The age of all the opal is not clear, although part is later than the zeolites since it is found replacing globular natrolite and also as veinlets traversing the rock. This later opal may have originated by the action of acidic ground waters on the zeolites since zeolites yield gelatinous silica (opal) when treated with acids.

CHEMICAL CHARACTER

The results of chemical and mineralogical analyses of specimens of the Tepee Creek formation are given in Table II.

TABLE II

	I*	II*	III*
SiO_2	16.38	39.53	
Al_2O_3	10.11	17.54	
Fe_2O_3	1.74	2.96	
MnO_2	0.05	0.03	
CaO	36.80	8.46	
MgO	1.02	5.50	
K_2O	0.48	0.41	
Na_2O	2.36	8.66	
CO_2	28.45	10.74	
H_2O	2.55	6.00	
Cl	0.11	0.13	
Total	100.05	99.96	
Mineral composition			
Calcite	60.05	none	1.77
Dolomite	4.26	22.28	none
Opal	10.57	11.59	46.20
Zeolites	25.12	66.13	52.03
Total	100.00	100.00	100.00

* Analyses by G. R. Mihram, chemist, Oklahoma Geological Survey.
I. 15 feet above base, Sec. 6, T. 4 N., R. 18 W.
II. 20 feet above base, Sec. 6, T. 4 N., R. 18 W.
III. Typical specimen from Sec. 26, T. 4 N., R. 17 W.

The mineral composition was determined as follows: (a) dolomite and calcite were computed from CO_2, CaO, and MgO; (b) material insoluble after hydrochloric acid treatment gives the amount of opal; (c) the remaining percentage gives the amount of zeolites.

Analysis II is representative of the average composition of the rock in the northwest outcrop, except that the carbonate ordinarily is not pure dolomite. Analysis III is to be compared with analyses I and II,

illustrating the variable content of carbonates and opal in the two localities.

Most of the calcium and magnesium are present in the carbonates, but a little is in the zeolites. Calcium and magnesium may, by base exchange, replace sodium of the zeolites without altering the space lattice, and it is probable that the calcium of the ground waters has replaced part of the sodium in the zeolites. A little calcium is also present as an impurity in opal.

All of the sodium and potassium are in the zeolites. The silica, water, and alumina are present both in zeolites and in opal.

FIELD RELATIONSHIPS AND AGE OF ZEOLITE-OPAL ROCKS

The zeolite-opal outcrop along the east bank of the North Fork of Red River appears to be horizontal and has a measured thickness of 47 feet. This outcrop is located on the south and west flank of an anorthosite hill, where the two rocks may be found in contact at varying elevations on the hillside. The zeolite-opal rock thus appears to rest on a sloping hillside of anorthosite. Furthermore, rounded pebbles of anorthosite are common in the overlying zeolite-opal mass. These features prove the anorthosite is older and that the Tepee Creek formation rests with an erosional unconformity on anorthosite.

In the inclined tunnel at this outcrop, vertical dikes of granite several inches wide and a few stringers of granite can be seen cutting the zeolite-opal rock. Hence the granite is younger. Since no igneous intrusions are known to cut the Cambrian or other sediments in the Wichita Mountain region, this granite is assumed to be pre-Cambrian. It represents, however, a much later time of igneous activity than that of the anorthosite because this basic rock is older, while the granite is younger than the erosional unconformity.

Moreover, the character of these granite dikes is somewhat different from the described granophyres and acidic dike rocks of the area which contain abundant intergrowths of quartz and alkali feldspar. The dikes which cut the Tepee Creek rocks contain no micropegmatite although they have approximately 10 per cent quartz. Other constituents are abundant microperthite and orthoclase, and minor amounts of biotite, zircon, and calcite. It seems likely that this dike originated from a magma much later than the one which produced the granophyres and anorthosite-gabbros.

The three Tepee Creek outcrops near Cold Springs, which cover many acres, are located close to the south edge of a large gabbro-anorthosite exposure (Fig. 1), but the two rocks were not found in contact. Numerous anorthosite pebbles, however, are present in the

zeolite-opal rock. No granite dikes were observed cutting the Tepee Creek formation at this locality. In Secs. 25 and 26, T. 4 N., R. 17 W., a chalk-like, calcareous material, a few feet thick, was encountered in several shallow water wells drilled near the southeast edge of the Tepee Creek outcrop. Whether the carbonate rock is a separate stratigraphic unit or a secondary alteration product is not clear from the data now available.

The most westerly of the zeolite-opal outcrops in T. 4 N., R. 17 W., is 8 miles distant from the one along the North Fork of Red River and the two areas can not be correlated directly in the field. A possibility exists that the eastern outcrops are not pre-Cambrian but later, perhaps Permian. They could be reworked pre-Cambrian zeolites or a Permian anorthosite-graywacke altered essentially to a zeolite-opal aggregate. The Tepee Creek sediments, however, have exceptional characteristics, no other rocks of this type having been described in the literature so far as the writers know. The peculiar characters common to all the zeolite-opal outcrops, therefore, strongly suggest they are the same in age, namely, pre-Cambrian.

ORIGIN

It is clear that most of the minerals now present in the Tepee Creek formation are of secondary origin, and the writers believe these minerals are alteration products of a sedimentary rock. The following evidence is given in support of the hypothesis that the original rock was sedimentary.

1. The rocks are distinctly layered; this layering in some places is due to mineralogical differences. One layer has 26.86 per cent dolomite and 4.79 per cent calcite; another layer has 4.26 per cent dolomite and 60.05 per cent calcite. Still another thin layer is composed of halloysite. Sorting also has produced layering for coarse pebbles of anorthosite are abundant in some outcrops, while in others the detrital fragments are microscopic in size. Both types of layering are interpreted as sedimentary bedding.

2. Many rounded anorthosite fragments are present. These are interpreted as pebbles, derived from the anorthosite. Also a few rounded and pitted sand (quartz) grains were observed in one specimen.

3. The abundance of dolomite (26.86 per cent) in one layer strongly suggests a sedimentary origin.

As to the character of the original rock, the following features are noted.

1. The zeolite-opal rocks contain many rounded fragments of

anorthosite which are fresh on the inside and altered on the outside, the outer shell being a fine-grained, gray mass of opal and natrolite. Furthermore, thin sections of the rocks show many labradorite fragments exhibiting albite twinning; many of these fragments are replaced along the edges and in the interior by opal and natrolite (Figs. 4 and 6). Ilmenite, a common accessory mineral in the anorthosite, invariably is present in the zeolite-opal rock. There is direct evidence, therefore, that at least part of the original rock was composed of anorthosite pebbles.

2. The local abundance of dolomite in these rocks suggests that it was a primary constituent, formed either contemporaneously with the original sediment or by replacement of limestone by magnesian solutions in a sea.

3. Although some of the calcite is epigenetic, as veins, most of it occurs as small grains within the rock mass. It is possible that part of the calcite, especially that in the northwest outcrop where it forms 60 per cent of one bed, could have been primarily deposited with the other sedimentary material as a limestone.

In summary, it seems likely that the original rock was composed largely of detrital anorthosite in the form of pebbles and small grains. Such a rock would be anorthosite-graywacke or anorthosite-conglomerate. Some dolomite, and perhaps limestone, were deposited contemporaneously with the graywacke; the carbonates, however, were more abundant in some of the sedimentary layers than in others. The thin bed of halloysite was derived from the alteration of aluminous silicates whose exact nature is not known.

At present the inner parts of the coarse anorthosite pebbles are essentially unaltered but the finer material has been almost completely changed to a compact mass of zeolites and opal.

The exact environment and agencies of alteration of anorthosite must have been of an uncommon type, for surface weathering of anorthosite does not produce extensive masses of zeolites and opal. However, zeolites are known to form by alteration of aluminous silicates in saline waters at normal temperature. Bradley[12] has described the occurrence of analcime beds, associated with meerschaum and chalcedony, in the lacustrine Green River shales (Eocene) of Wyoming. He attributes the origin of the analcime to the reaction of saline waters on volcanic ash deposited in the water. Ross[13] interpreted the analcime

[12] W. H. Bradley, "Occurrence and Origin of Analcite and Meerschaum Beds in the Green River Formation of Utah, Colorado, and Wyoming," *U. S. Geol. Survey Prof. Paper 158* (1929), pp. 1–7.

[13] C. S. Ross, "Sedimentary Analcite," *Amer. Min.*, Vol. 13 (1928), pp. 195–97.

in Yavapai County, Arizona, as probably formed by the action of saline waters on colloidal clay aluminum silicates under playa conditions. Phillipsite is found as a diagenetic product in deep-sea dredgings, apparently formed by the alteration of volcanic dust on the sea floor.[14]

It seems probable that the Tepee Creek formation was laid down in a sea and the alteration was accomplished by the saline constituents of the water. That is, the formation of the zeolites was a diagenetic process, probably due to the action of sodium chloride on the labradorite of an anorthosite-graywacke.

Some of the opal occurs as veinlets traversing the rock and as replacements of natrolite, proving that this part of the opal is younger. This mineral may have developed by the gelatinizing action of acidic ground waters on zeolites. It is also possible that some of the opal may have been formed contemporaneously with the zeolites on the pre-Cambrian sea floor by the alteration of anorthosite fragments.

GEOLOGIC SIGNIFICANCE OF TEPEE CREEK SEDIMENTS

The discovery of the Tepee Creek formation indicates the pre-Cambrian history of the Wichita Mountains is more complex than has been recognized previously. A new kind of sediment and period of sedimentation, a new unconformity, and a new period of igneous activity are added to the knowledge of the pre-Cambrian geology of this area.

The unconformity between the Tepee Creek sediments and the anorthosite indicates uplift and erosion. The anorthosite, being medium- to coarse-grained, must have cooled at some depth below the surface. This area was uplifted and eroded until the anorthosite was exposed at the surface, an action requiring a long period of time. The basic igneous rock then subsided and was covered by a sea in which the anorthosite-graywacke was deposited.

At a still later time granite dikes intruded the Tepee Creek sediments. These dikes are only a few inches thick, yet they are medium-grained. This may indicate that they were injected at some depth and not as near-surface types. The Tepee Creek formation thus may once have been considerably thicker than is now represented or else it was covered by younger sediments. Furthermore, the magma which formed these dikes was generated after the cooling, uplift, and erosion of the anorthosite. Hence the anorthosite-granophyre magma is much older than the post-Tepee Creek granite magma.

[14] J. Murray, and J. Hjort, *The Depths of the Ocean*, pp. 159–60. Macmillan and Company, London (1912).

The lower Paleozoic sediments on the flanks of the igneous rocks of the Wichita Mountains have steep dips away from the mountains, while the pre-Cambrian Tepee Creek rocks are apparently horizontal. This condition implies that the central part of the Wichitas has not suffered much differential folding since the deposition of the Tepee Creek sediments and that the igneous core acted as a unit in a horst-like uplift.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 2 (FEBRUARY, 1941), PP. 300-317, 11 FIGS.

LA ROSA FIELD, REFUGIO COUNTY, TEXAS[1]

BARNEY FISHER[2]
Dallas, Texas

ABSTRACT

The La Rosa field was discovered in September, 1938, as a result of geophysical work preceded by detailed subsurface mapping. There are at present 72 oil wells producing from six separate sands ranging in depth from 5,400 to 6,300 feet, and there are six gas wells which are completed in three different gas sands. The producing area is cut by a normal fault downthrown toward the southeast and the upthrown side produces only gas. The field proper is located on the downthrown side and produces both gas and oil. This field exhibits a type of structure which is common to producing areas in the lower Gulf Coast; that is, an anticlinal fold of low relief on the downthrown and downdip side of a normal fault. Of particular interest is the fact that nearly all structural movement within the field occurred previous to the end of Frio deposition and little or no structure is observed in formations younger than the Frio.

INTRODUCTION

The La Rosa field is located in the southern part of Refugio County in the lower Gulf Coastal region of Texas. It is located in the so-called Frio trend which is characterized by a maximum development of the sands in the Frio formation which shale out within short distances both up and down the dip. Most of the fields along this trend are very prolific and produce an excellent grade of crude oil.

Approximately 10 miles northward is the Refugio field, and the Plymouth field in San Patricio County is about the same distance south. The field is reached by a paved highway from the town of Woodsboro 5 miles north.

The use of electrical logs and careful coring has made the interpretation of structural conditions a relatively simple problem, and by means of core analysis much valuable information concerning the characteristics of the oil sands has been obtained.

EXPLORATION AND DISCOVERY

The reflection seismograph must be given credit for the discovery of La Rosa field, although exploration by seismograph was preceded by detailed subsurface work which indicated a large positive area south of the town of Woodsboro. It was felt that there were possibilities of localized structure on this large feature and a reconnaissance survey by reflection seismograph revealed some structural closures within the field and northwest of the present field. After this survey was made a block of leases was assembled and the seismic data re-

[1] Read before the Association at Chicago, April 13, 1940. Manuscript received, August 15, 1940.

[2] Chief geologist, Coronado Corporation.

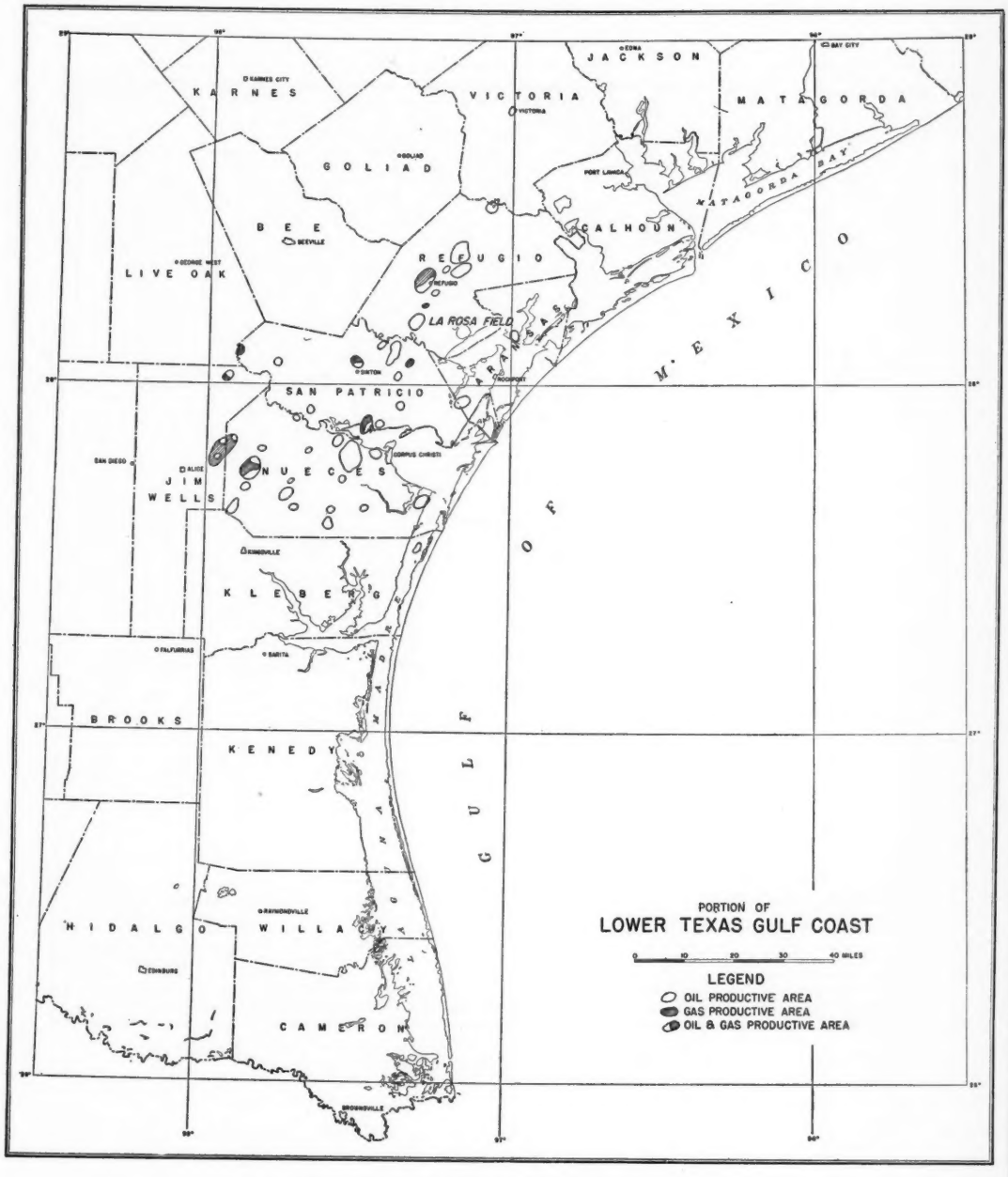

FIG. 1.—Location of La Rosa and some near-by producing areas.

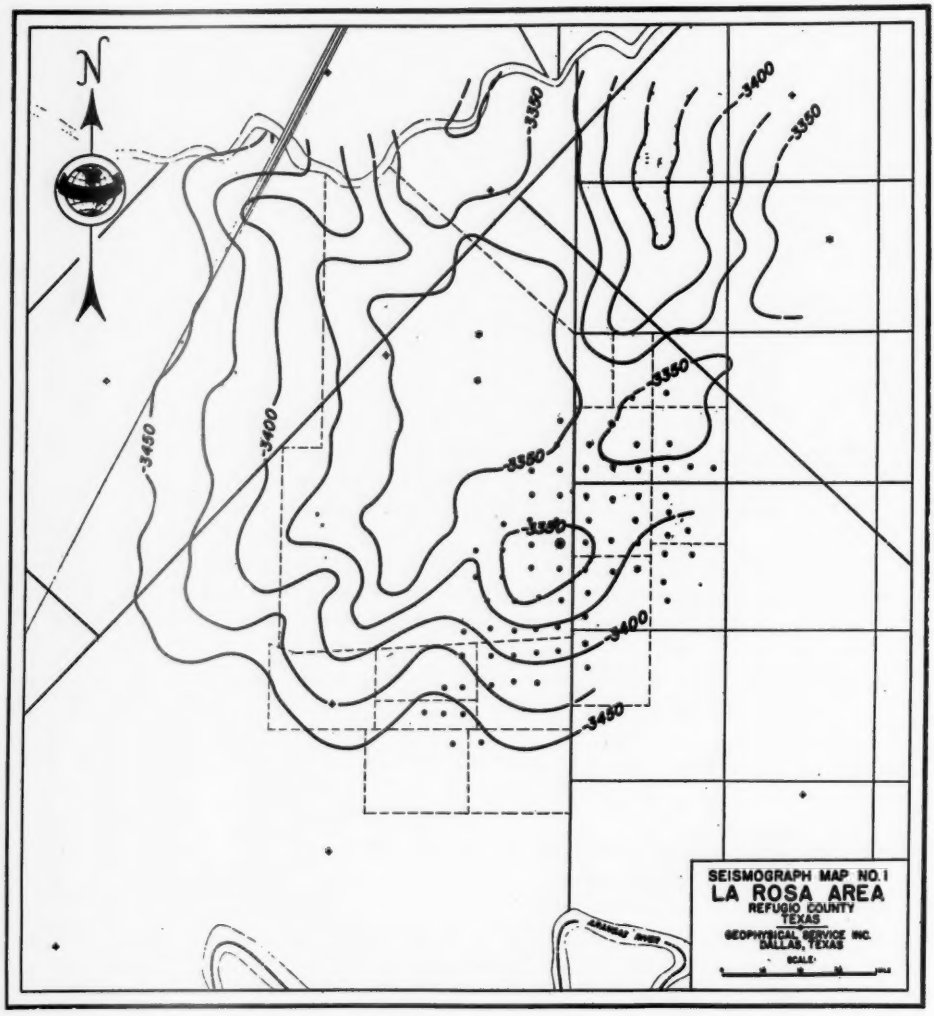

FIG. 2.—Original reflection-seismograph map of La Rosa area.

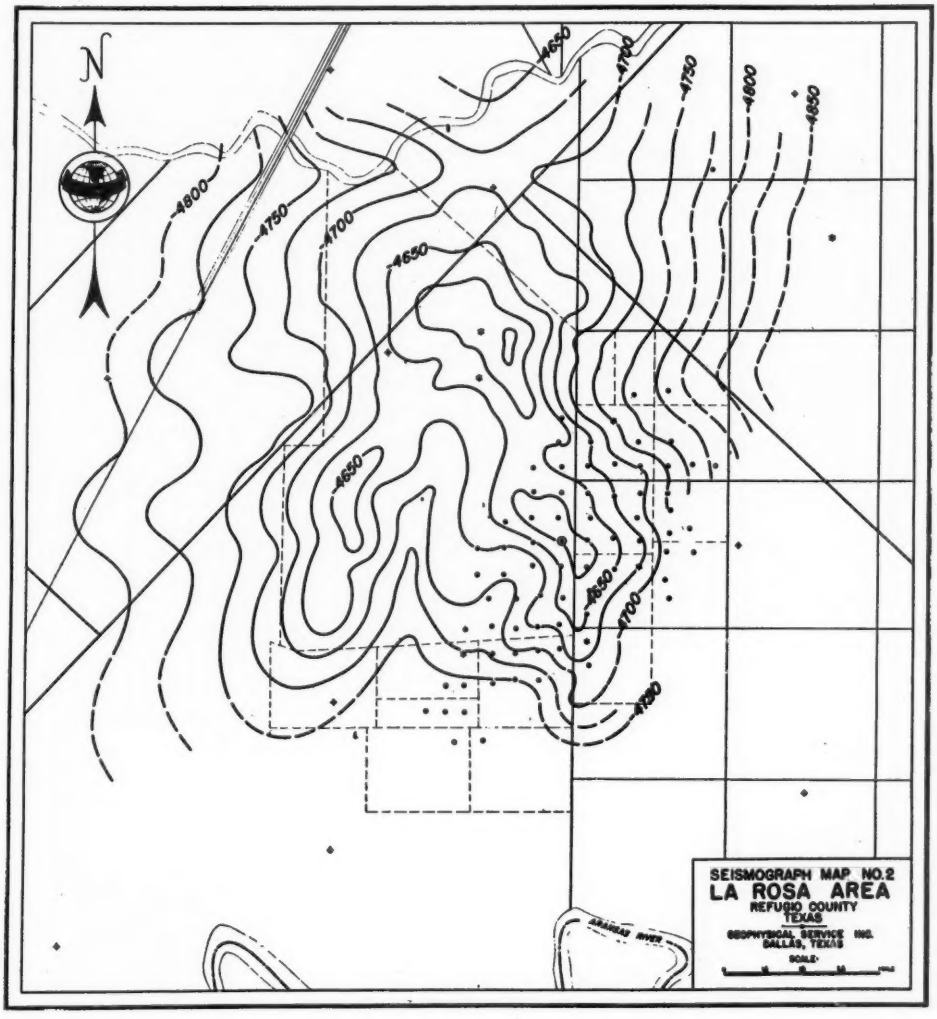

FIG. 3.—Map of La Rosa area on bed deeper than that used for original seismic map.

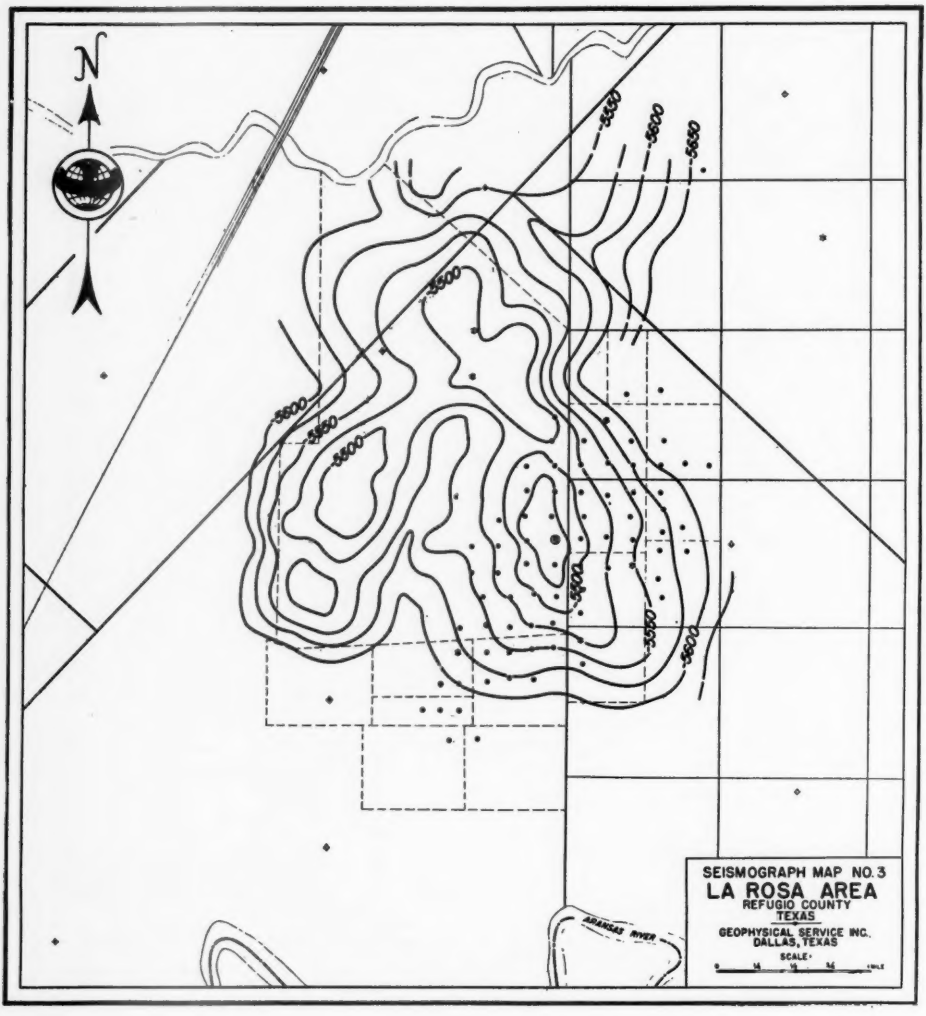

FIG. 4.—Final reflection-seismic map of La Rosa area.

worked on a deeper bed in order to check the original map. It was felt that additional seismic data were necessary before an accurate location for a test well could be made. The area was, therefore, re-surveyed in detail by reflection seismograph and produced results which were similar to the original data, but the reflections worked were at sufficient depth to be well into the Frio zone.

There was some evidence of faulting indicated, but the location of the fault could not be definitely established by means of the seismograph records. The reëntrant syncline in the southwest part of the area was also suggestive of faulting. Of the three structurally high areas shown in Figure 4, the one at the extreme southeast was considered to be the most promising for oil accumulation, since, if faulting were present, this area would be on the southeast, or downdip, side of the fault. The first well was begun in the spring of 1938 but was temporarily abandoned when it encountered the Greta sand abnormally low. This, however, was considered as additional evidence that the well was on the downthrown side of a fault. The second well was located about 1½ miles northwest of well No. 1 and was drilled to a depth of 6,900 feet, but encountered no oil sands at that depth. It did, however, penetrate a gas sand about 50 feet in thickness at a depth of 5,350 feet. The well was completed in this sand as a very large gas well.

A study of the log of the second well and other wells in the area revealed a pronounced thinning of the Greta sand toward the east. This indicated the possibility of finding the Frio beds high in the vicinity of well No. 1 and was substantiated by further examination of the seismic data. Work was shortly resumed on this well and on September 7, 1938, it was completed as a commercial oil well in a sand in the Frio zone at a depth of 5,900 feet. Subsequent development has shown that this well was located almost in the center of the productive area.

STRATIGRAPHY

There is some question as to the classification of the formation exposed at the surface in this area. Part of the area at least is covered with Beaumont clay. The beds exposed in the gas-producing area on the upthrown side of the fault may represent an inlier of the Lissie formation. The base of the Lissie-Goliad group is tentatively placed at 1,600 feet. These beds are, as elsewhere, predominantly sandy. Below the Lissie there are 1,075 feet of Lagarto composed of alternating sands and shales. Below the Lagarto are about 740 feet of Oakville sands. Below this group is the Catahoula formation, which consists of about 300 feet of shale at the top and 400 feet of sandy beds which

contain *Ostrea* shells and lignite in the lower part. Below the Catahoula is the *Discorbis* zone, which is about 275 feet in thickness, consisting almost entirely of blue-gray shales. The *Heterostegina* zone underlies the *Discorbis* zone and is composed of medium-fine sands with thin beds of shale in the upper part and entirely sand in the lower half. This zone is approximately 225 feet in thickness. This figure may be somewhat in error due to the fact that it is difficult to determine the exact point of contact with the underlying Frio. The large sand body known as the Greta sand is 200 feet in thickness in this area and it is believed by the writer that at least the lower third of the thick sand body is of Frio age. The top of the Frio in the discovery well is therefore placed at a depth of 4,650 feet and all formations encountered below this depth down to a depth of 6,900 feet are Frio in age. Numerous sands occur within the Frio group and most of them contain either gas or oil. The sands are mostly very coarse-grained and are light gray in color.

STRUCTURE

The most widely used unit for subsurface contouring in this area is the *Heterostegina* zone, or, if electrical logs are available, the Greta sand is used. Figure 5 shows structure contours drawn on top of the Greta sand. It is apparent from a study of this map that an oil field occurring under conditions similar to those at La Rosa might be completely overlooked, if deeper formations were not considered in constructing subsurface maps. At this horizon the highest area is approximately 2 miles northwest of present production. The area which is underlain by the Frio structure is indicated only by a slight flattening off the east flank of a large southward-plunging anticlinal nose.

Figure 6 illustrates structure contours drawn on top of the 5,900-foot oil sand. Obviously a pronounced unconformity exists between the Frio and the *Heterostegina* zones. This unconformity is shown clearly by the fact that wells on the highest part of the structure in the oil-producing area are higher than the dry hole west of the two gas wells on the upthrown side of the fault. Also, it is strikingly illustrated by a comparison of the logs of these gas wells and the dry hole immediately west. In this area the dip in the Frio beds is westward while the dip in the Greta sand and overlying beds is eastward. The faulting is well developed at this level and has been definitely established by the southernmost of the two gas wells on the upthrown side of the fault which intersected the fault plane at a depth of 4,750 feet. It is doubtful if this fault occurs above the Frio. The Hewitt-Dougherty's Rooke No. A-1 at the extreme southwest edge of the field is a very

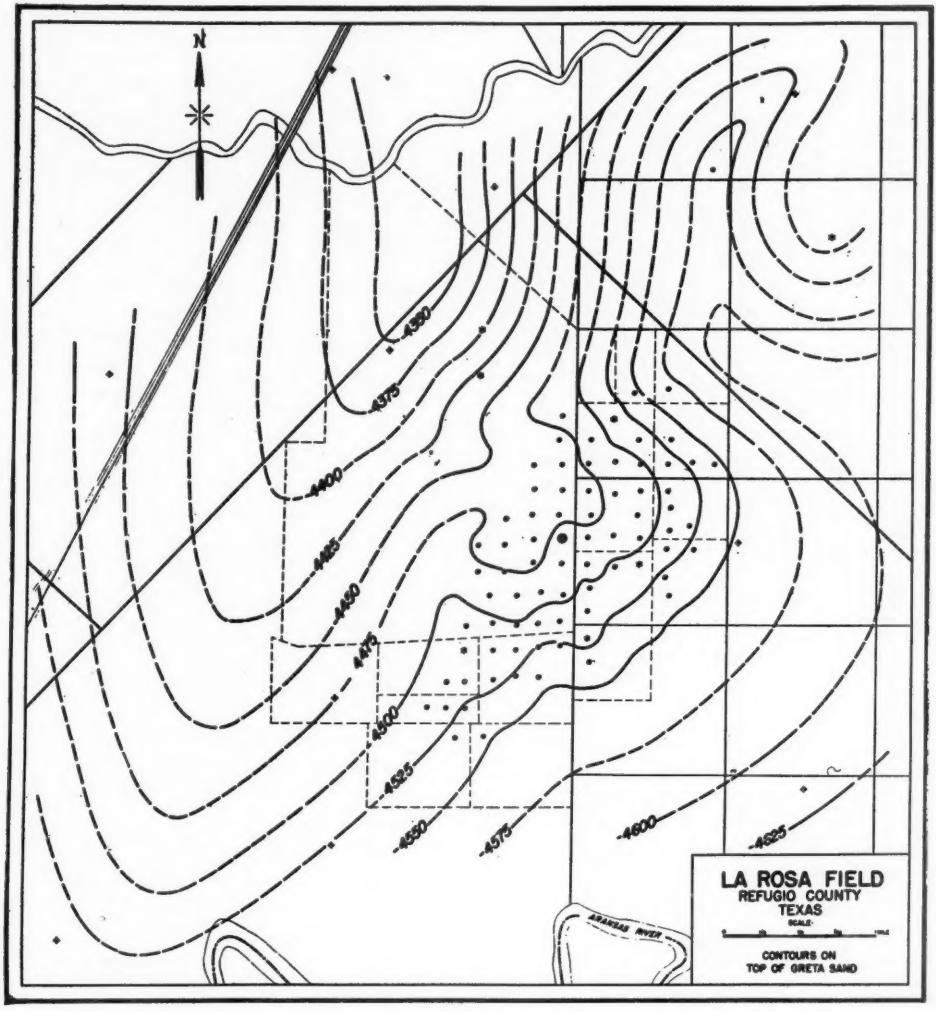

FIG. 5.—Contours on top of Greta sand.

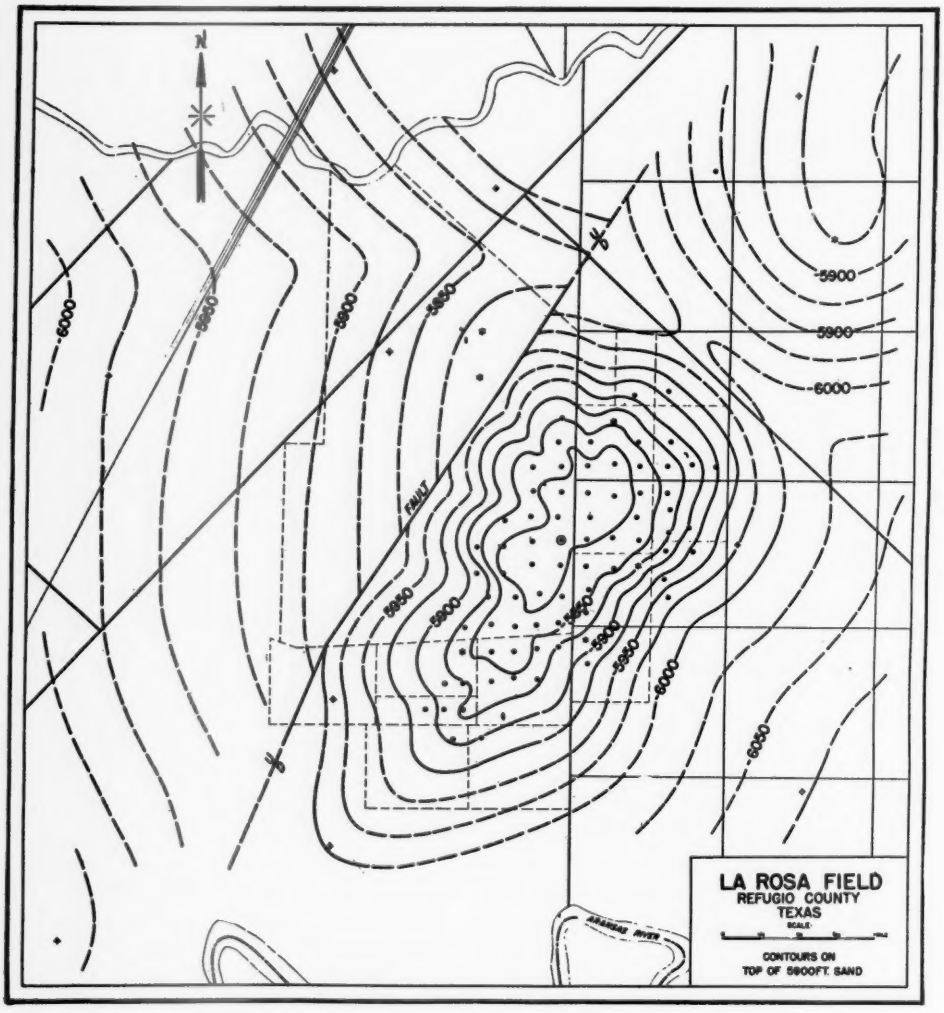

FIG. 6.—Contours on top of 5,900-foot sand.

low well with a lengthened section and is believed to be near the fault on the downthrown side.

The extent of folding previous to the end of Frio deposition is clearly shown by Figure 7, which is an isopach map drawn on the interval between the top of the Greta sand and the top of the 5,900-foot sand. The similarity between this isopach map and the structure map of the 5,900-foot sand indicates that the local folding occurred almost entirely before the end of Frio time.

A structure-contour map of the 6,300-foot oil sand is shown by Figure 8. This map does not represent true structure, due to the lenticular nature of the sand. The highest point on the 6,300-foot sand is somewhat east of the highest point on the 5,900-foot sand. The 6,300-foot sand is the upper part of a very thick series of sand comprising what is locally known as the "Tom O'Conner" sand. The upper part of this sand is replaced by shale westward and forms the equivalent of closure on the western side of the producing area. A line has been drawn on the map limiting production to the west where all of the sand above water level has graded completely into shale.

OIL-PRODUCING SANDS

There are at present six producing oil sands in the field, all of which are within the Frio formation. The shallowest of these sands occurs at a depth of approximately 5,400 feet. This sand is a thin stringer which is present on the east and southeast flanks of the structure and reaches a maximum thickness of 10 feet. There are at present eight wells completed in this sand and the oil is the lowest-gravity crude produced in the field. The sand is somewhat shaly and does not have the high permeability and porosity characteristic of most of the other sands in the field. At the highest points this sand produces gas, but lower on the flanks, contains oil. The water level is at present undetermined.

The 5,700-foot sand is a lenticular sand body ranging from 0 to 15 feet in thickness and is present on the east, south, and west flanks of the structure. This sand also contains gas where it is found high on the structure and is oil-saturated at lower levels. The productive limits of this sand have not been defined at present. There are 12 wells producing oil from this zone. In places the sand is very hard and calcareous, but oil wells have been completed in it even at locations where the porosity is so low as to be scarcely legible on an electrical log.

The 5,900-foot, or discovery, sand is clean, coarse-grained sand ranging from 80 to 100 feet in thickness and containing a maximum oil column of 30 feet. On top of the structure, the sand contains a gas cap about 25 feet thick. This sand averages about 32 per cent

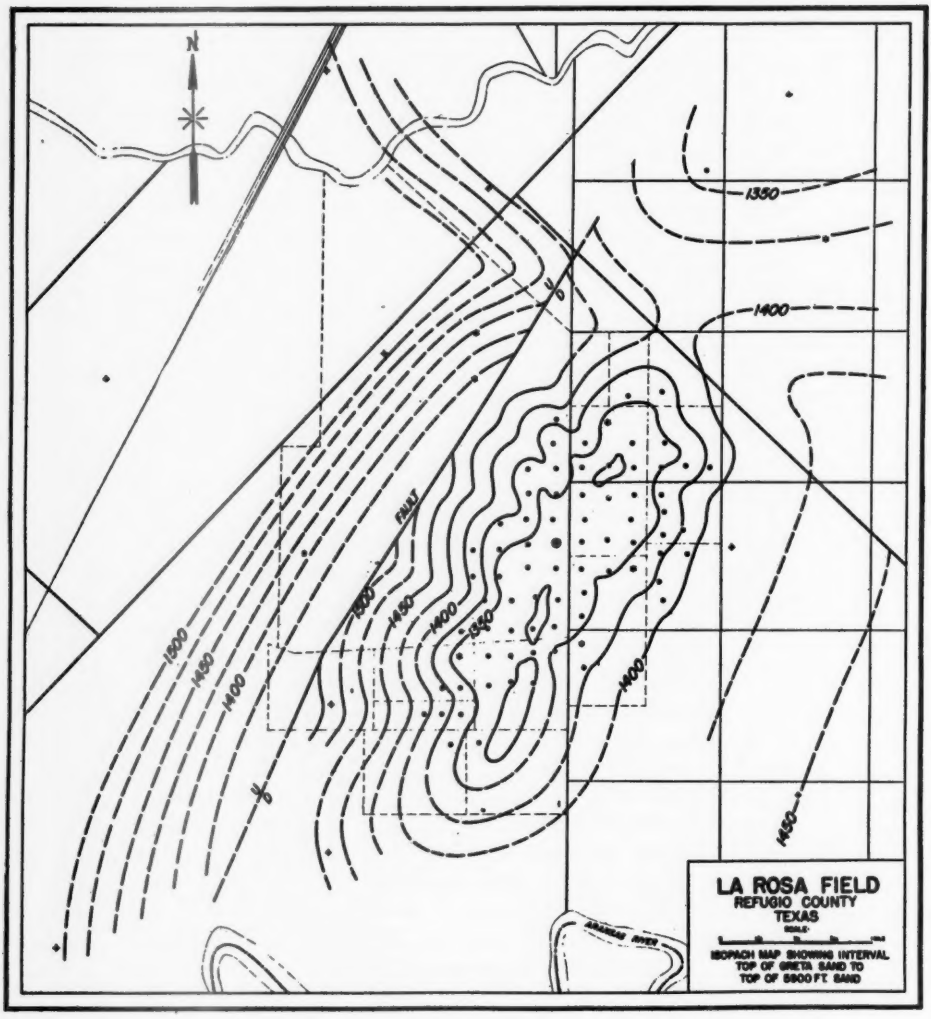

FIG. 7.—Isopach map showing interval from top of Greta sand to top of 5,900-foot sand.

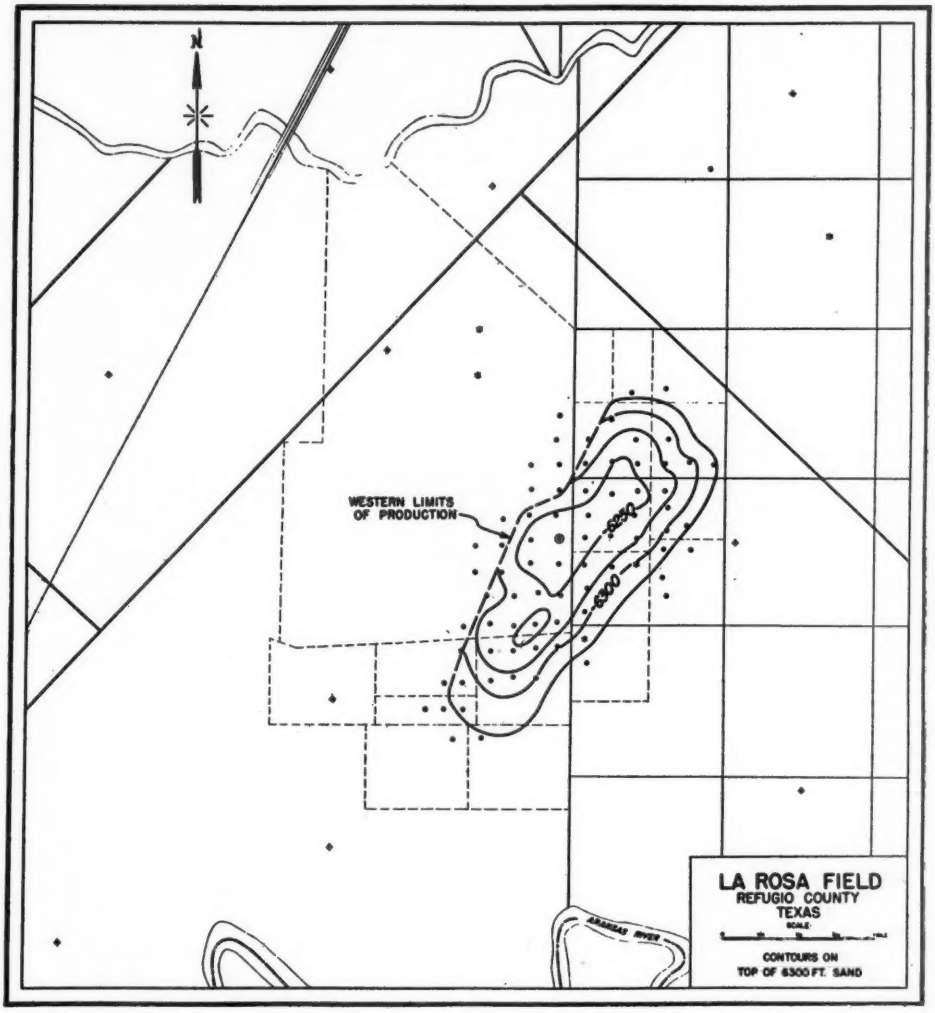

FIG. 8.—Contours on top of 6,300-foot sand.

porosity, and its permeability averages approximately 2,000 millidarcys. Careful laboratory measurements have indicated that the ultimate recovery from this sand should be 975 barrels of oil per acre foot. There are 22 wells producing from this sand and the producing area, which covers approximately 910 acres, has been defined in all directions.

The 6,100-foot sand is a thin lens which was discovered by the Rutherford and Royal Oil and Gas Corporation's Schirmer No. 1-B which is the extreme northeast well of the field. This sand has a thickness of about 10 feet and since this is the only well which has encountered this sand, the producing area is not known but is undoubtedly small.

The 6,250-foot sand has only one well producing from it, the Phillips' Paweleck No. 1, a west offset to the aforementioned 6,100-foot well. This sand has a thickness of about 15 feet and has been found in a few other wells in the field, but has contained gas except in this well.

The 6,300-foot sand was discovered by the Rutherford and Royal Oil and Gas Corporation's Schirmer No. A-1 on the northeast flank of the structure. This sand has a zone of saturation reaching a maximum thickness of 40 feet and in the eastern part of the field is a very uniform coarse-grained sand body. Toward the west, however, this sand breaks into a number of thin stringers and finally grades into shale in the western part of the field. The present producing area covers approximately 1,000 acres and is productive in 28 wells.

GAS SANDS

The Frio section encountered in this area has, in addition to the previously described oil sands, four gas-bearing sands, the shallowest of which occurs at approximately 4,900 feet. No wells have been completed in this sand but it has been cored and tested in several wells and the gas is relatively dry. This sand is about 60 feet thick in the eastern part of the field but thins within a short distance westward and disappears at about the top of the structure.

The so-called 5,400-foot sand contains gas on both the upthrown and downthrown sides of the fault and has a thickness of about 60 feet. Two wells on the upthrown side of the fault have been completed in this sand and are being produced. In addition to the gas, these wells make about one barrel of water-white condensate for each 100,000 cubic feet of gas.

The 5,600-foot sand has a uniform thickness in the entire area of about 40 feet. There has been one well completed in this sand, which is shut in. Tests have indicated that this zone is rich in distillate.

The 5,800-foot sand is a persistent bed on the downthrown side of the fault and is uniformly 15 feet thick. Three wells have been completed in this sand and have shown that the gas is very high in distillate content.

A recycling plant, now under construction, will remove distillate from this sand and later from the 5,600-foot sand. It is estimated that approximately 5 million barrels of distillate can be recovered from these two sands.

In the southwest part of the field sands which contain gas have been encountered at a depth of about 6,250 feet, but the lateral distribution of these sands is limited and they are not considered of much importance.

CROSS SECTIONS

Two cross sections have been constructed from electrical logs along the lines AA' and BB', as shown in Figure 9. Section AA' is a northwest-southeast section which extends from The Texas Company's Rooke No. 1, which is an old dry hole in the northwest part of the field, to the southeast edge of the productive area. This section illustrates the fault which intersects the area and shows clearly the replacement of sand by shale updip. Also, the degree of unconformity between the Frio beds and the Greta sand which occurs at about 4,500 feet is clearly shown, together with the rapid thinning of the Greta eastward. The gas-oil and oil-water contacts in the 5,900- and 6,300-foot sands are also shown. It is evident that little structural movement has occurred in the field in the beds less than 4,500 feet in depth.

Section BB' is a southwest-northeast section which follows the axis of the fold and extends for a distance approximately one mile beyond the northeast and southwest productive limits. The 5,700-foot and the 6,250-foot zones are illustrated more clearly on this section than on section AA'. A slight arching of the strata at depths less than 4,500 feet is shown by this section and corresponds with the nosing in the shallow beds shown on Figure 5.

From a study of the sections it is assumed that the fault and settling of the Frio strata adjacent to the fault plane probably occurred simultaneously and this movement must have been completed at the end of Frio time. This assumption is borne out by the fact that the reverse dip into the fault plane is almost exactly equal to the displacement of the fault. Whether the folding was caused by the fault movement, or whether the reverse is true, is of little consequence since the fault is of secondary importance insofar as oil accumulation is concerned, all of the oil accumulation occurring on the fold and not against the fault plane.

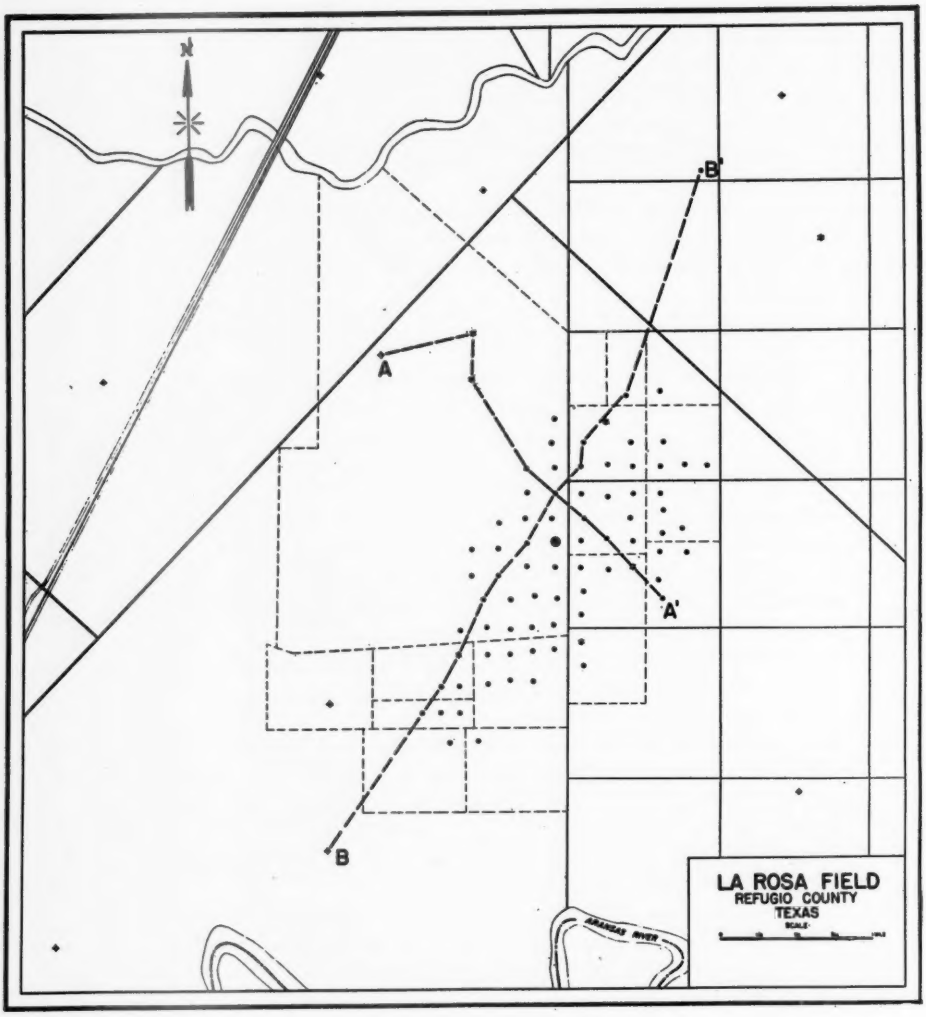

FIG. 9.—Location of cross sections.

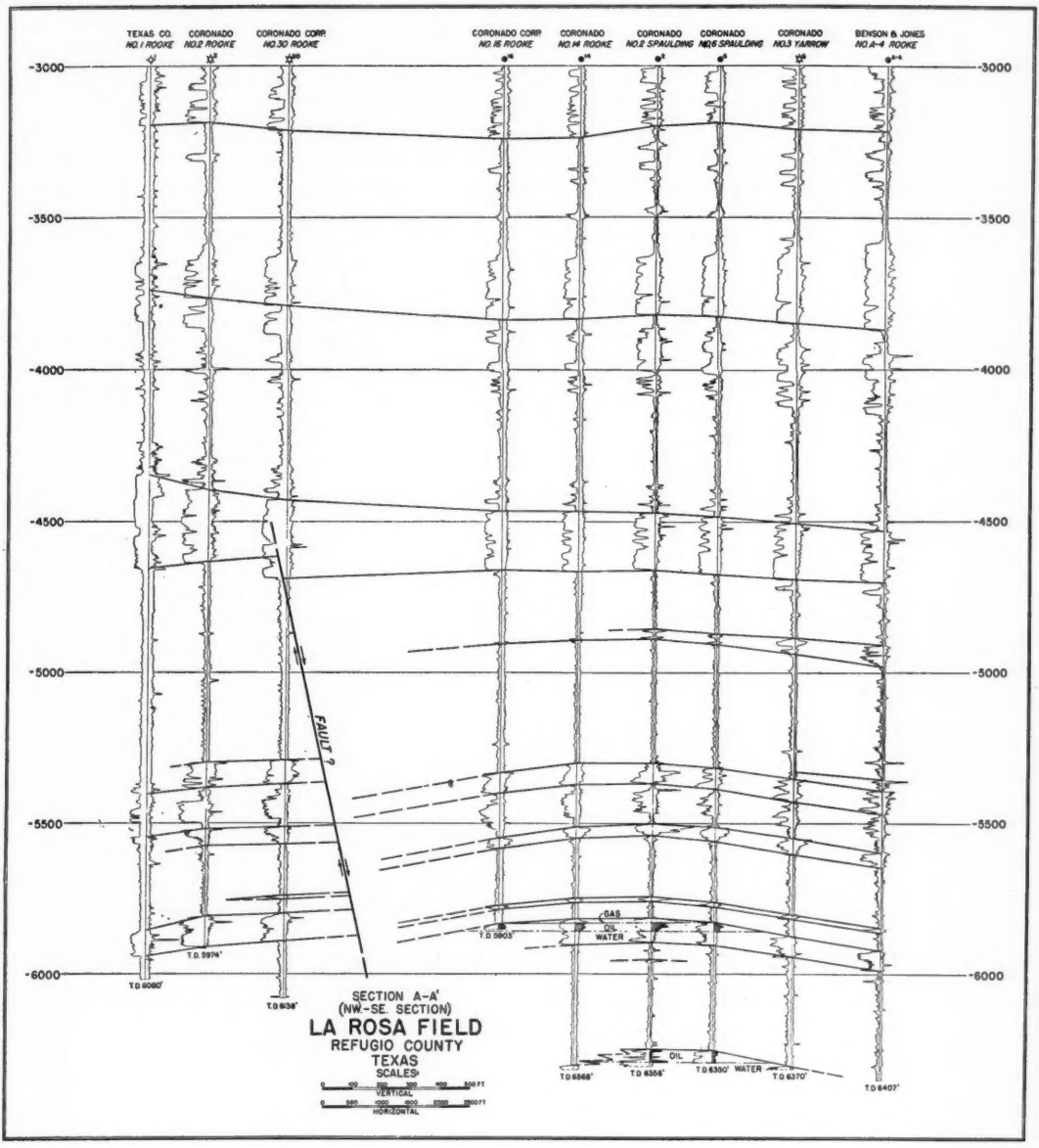

FIG. 10.—Section *AA'*.

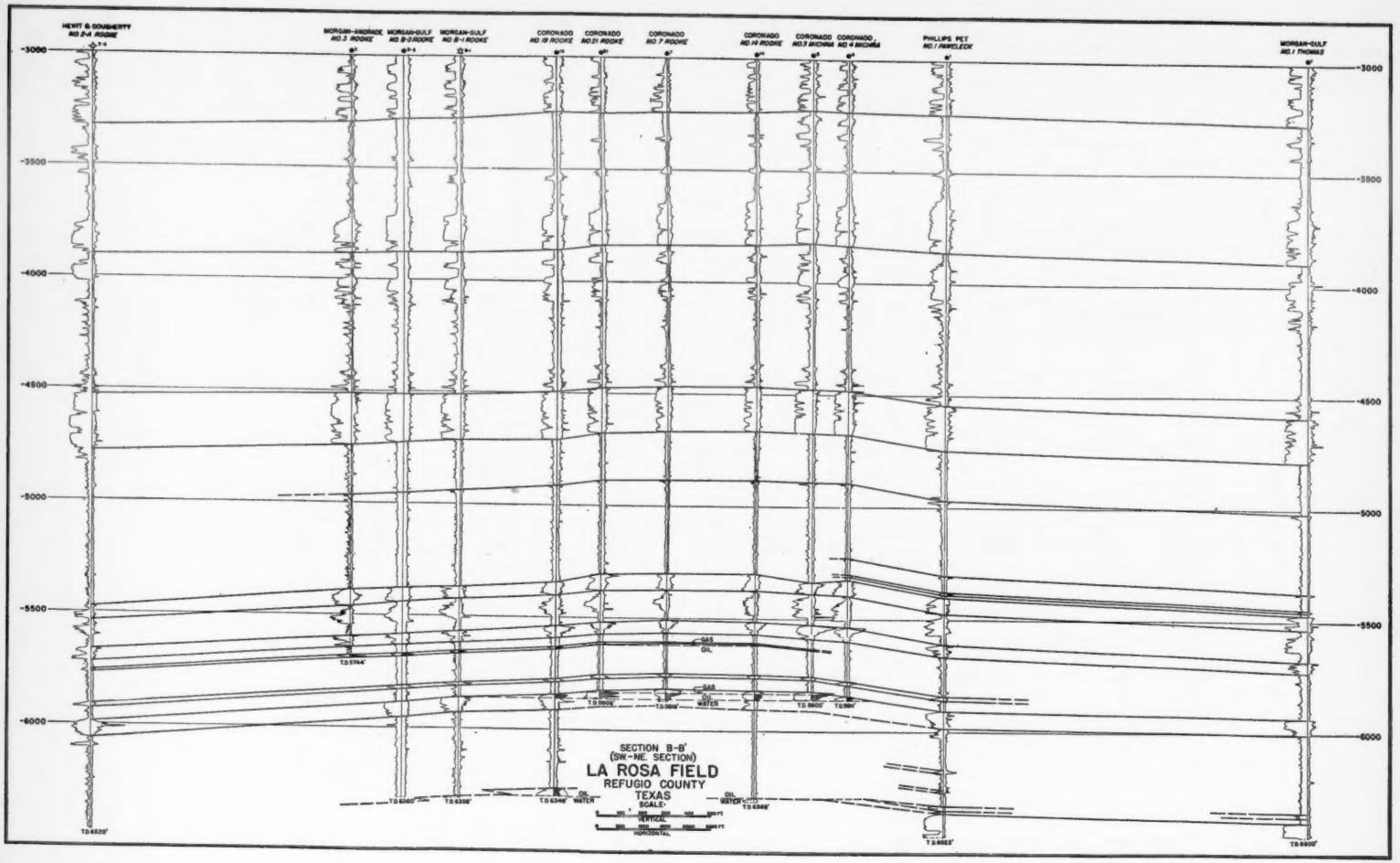

FIG. 11.—Section *BB'*.

DRILLING AND PRODUCTION METHODS

The wells are drilled with heavy rotary equipment and are completed in 15–20 days. The common practice is to set approximately 1,400 feet of $10\frac{3}{4}$-inch welded surface casing and an oil string of $5\frac{1}{2}$-inch casing cemented with 600 sacks of cement. The wells are completed by gun-perforating the casing after squeezing cement above and below the points to be perforated. Coring is done with wire-line coring equipment. It has not been found necessary to use screens since the sands are firm and the wells make no appreciable amount of sand except when first completed. The gas-oil ratio averages about 500 cubic feet of gas per barrel of oil produced and the gravity of the oil is above 40° A.P.I., which grade of crude brings the top price for this type of oil. The field is served by two 6-inch pipe lines to Corpus Christi, Texas.

ACKNOWLEDGMENT

The writer is indebted to Coronado Corporation for permission to publish this paper and to Robert S. Taylor for preparation of maps. Appreciation is expressed to many individuals who have made helpful suggestions.

FIG. 11.—Section *BB'*.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 2 (FEBRUARY, 1941), PP. 318-323, 1 FIG.

GEOLOGICAL NOTES

MIDLAND, TEXAS, INSOLUBLE RESIDUE STUDY GROUP[1]

TAYLOR COLE[2]
Midland, Texas

The Midland Insoluble Residue Study Group was organized in November, 1939, mostly through the efforts of John Emery Adams, Taylor Cole, W. Lloyd Haseltine, P. D. Moore, and Dana M. Secor. Cole served as chairman of the group until May, 1940, and C. M. Linehan has served since that time.

Several objectives were in mind when the group was organized. The immediate object was to secure insoluble residues on as many as possible of the Ellenburger cuttings throughout the West Texas area. When this had been done attention was turned to other pre-Permian rocks (middle and upper (?) Ordovician, Devonian, Mississippian, and Pennsylvanian) and finally to the Permian itself (San Andres and lower).

In order to standardize the work as much as possible, a classification of the insoluble residues has been prepared by P. D. Moore and Taylor Cole; and an index set of chert residues prepared and labeled.

The labor and expenses of the group have been shared by the participating companies of which there are 20. The laboratory facilities have been furnished by The Standard Oil Company of Texas and Shell Oil Company, Incorporated.

The samples are dissolved in dilute hydrochloric acid which is donated by Dowell Incorporated. The percentage of residue by weight has been kept for all Ordovician samples and for many others. When this procedure is not followed, a constant amount of sample is used for dissolving when it is practicable. These records and samples are all filed in the University Lands office where they are available at all times to the participating companies.

A few more than 12,000 samples have been prepared from 78 wells at a maximum cost of $40 to any participant or a cost of 3.3 mills or less per sample!

Meetings have been held from time to time to discuss various problems as well as papers on the subject by workers in other areas.

Membership in the study group is necessarily limited to representatives of the companies which share in the costs.

[1] Manuscript received, November 30, 1940.

[2] Research geologist, University Lands.

MIOCENE FISHES IN WELL CORES FROM TORRANCE IN SOUTHERN CALIFORNIA[1]

LORE DAVID[2]
Pasadena, California

This illustration was unfortunately omitted from the geological note by Miss David in the December, 1940, *Bulletin*.

Section of well core showing three specimens of Lanternfish, *Lampanyctus* n. sp., No. 16112 U. S. Nat. Mus. Coll. Diameter of core about 100 mm.

[1] Manuscript received, November 2, 1940.

[2] Divison of the geological sciences, California Institute of Technology.

AGE OF ABYSSAL DEPOSITS OF EAST INDIAN ARCHIPELAGO[1]

CARL C. BRANSON[2]
Evanston, Illinois

Deposits of sediments considered to have formed in deep seas are widespread in the islands of the East Indian Archipelago. They occur in a broad belt across central Borneo and on eastern Celebes, eastern Ceram, Savu, Timor, and Rotti. Two general types of abyssal sediment occur, radiolarian sediments and red clay. The common type of radiolarian sediment is hornstone or "chert" which is composed almost entirely of radiolarian tests and silica cement. Radiolaria also occur in siliceous limestone, in diabase tuff, and in marly limestone. In places red clay is associated with the radiolarian sediments, and much of the red clay contains Radiolaria. That the red clay accumulated in abyssal seas is shown by its resemblance to deep-sea dredgings of red clay in chemical analysis, presence of nodules of manganese, abundance of Radiolaria and fish teeth, lack of stratification, and occurrence of recognizable clastic grains of volcanic glass.

The stratigraphic position of the deposits does not establish close limits to their age. In Borneo the deposits (Danau formation of Molengraaff) overlie slates of unknown age and are overlapped by late Tertiary sediments and volcanics.[3] Since they are strongly folded and are unconformably overlain by late Tertiary deposits, they antedate the Miocene (?) orogeny. Limestone associated with the radiolarian hornstones of Rotti and Savu and a similar limestone overlain by red clay on the Noil Tobee in Timor contain lamellibranchs identified as *Halobia* and *Daonella*, both Triassic genera. The Timor occurrence is doubtful.

Paleontological evidence is conflicting. A Cretaceous foraminifer occurs in associated rocks in Borneo. The radiolarian fauna of the Danau formation consists of 100 species, of which 83 are unique. Of the remaining 17, two are cosmopolitan from upper Paleozoic to Cretaceous, one occurs in the Permian of western Liguria, Italy, 12 occur in the Jurassic of central Europe, and four in the Jurassic of California. The age is determined as pre-Cretaceous, probably Jurassic.[4] The radiolarian faunas of Rotti and Savu occur in limestones

[1] Manuscript received, December 11, 1940.

[2] Northwestern University.

[3] G. A. F. Molengraaff, "On the Oceanic Deep Sea Deposits of Central Borneo," *Kon. Akad. Wetensch. Amsterdam, Proc. Sect. Sci.*, Vol. 23, Part 2 (1910), pp. 141–47.

[4] G. J. Hinde, "Description of Fossil Radiolaria from the Rocks of Central Borneo," *Geol. Verk. in Centraal-Borneo, 1893–1894*, Appendix 1. Leiden (1900).

containing the Triassic lamellibranchs, *Daonella* and *Halobia*, and the Jurassic belemnite, *Asteroconites*, occurs in these limestones in Savu. The two islands yield 71 species of Radiolaria, of which the sole species which occurs outside of the area is from the Jurassic of Italy and Switzerland. The age is said to be Triassic.[5] Hornstone pebbles of Ceram and eastern Celebes yield 20 species of Radiolaria, one of which occurs in the middle Muschelkalk of Hungary. This fauna is assigned to the Triassic. A single species from Timor was found in a pebble of the *Halobia* limestone.

A vertebrate fauna has been described from the Noil Tobee, central Timor, from red clay above the *Halobia* limestone.[6] The age was determined to be Upper Cretaceous on the basis of elasmobranchs, a pycnodont, and a mosasaur.[7] No information is available concerning the position of the fossils in the outcrop. An additional fauna from the same locality has been described by Weiler[8] and referred to the Upper Cretaceous. Critical analysis of this fauna shows that it contains lower Permian elements. Weiler's *Carcharodon* sp. (Pl. 12, Fig. 39) is almost certainly the crown of an edestid, probably of *Helicoprion*, a Permian genus. His enchodont (Pl. 12, Figs. 31–32) is *Ancistriodus*, a genus known only from the Phosphoria of Wyoming. The spine referred to Hybodontidae (Pl. 12, Figs. 20–22) is a species of *Arctacanthus*, a genus heretofore known only from the middle Phosphoria of Wyoming and from the lower Permian of Cape Stosch, East Greenland. Most of the other teeth figured are preserved as enamel sheaths of crowns and the specimens might just as well belong to such late Paleozoic genera as *Cladodus* and *Pleuracanthus* as to Cretaceous genera. That Weiler's fauna probably comes from more than one period is indicated by the presence of *Ptychodus* and of the Jurassic genus *Strophodus*. These probably came from higher levels of the outcrop and from the same zone as the forms described by de Beaufort.

The ages indicated for the various deposits are as follows.

Upper Cretaceous	Upper part of red clays of Timor containing vertebrate fauna of de Beaufort and of Weiler in part.
	Foraminifer of Borneo.

[5] G. J. Hinde, "Radiolaria from Triassic and Other Rocks of the Dutch East Indian Archipelago," *Jaarb. Mijnw. Ned. Oost-Indie*, Vol. 37 (1908), pp. 694–736.

[6] L. F. de Beaufort, "On a Collection of Upper Cretaceous Teeth and Other Veterbrate Remains from a Deep Sea Deposit in the Island of Timor," *Jaarb. Mijnw. Ned. Oost-Indie*, Vol. 49, Verh. Part 4 (1923), pp. 55–71.

[7] E. von Huene has recently discussed this and other Timor mosasaur remains. "Mosasaurier-Zähne von Timor," *Centralbl. Min.* (B), Jahrg. 1935 (1935), pp. 412–16.

[8] Wilhelm Weiler, "Ueber Fischreste aus der Kreide von Timor," *Neues Jahrb. Min., Beil.-Bd.*, Vol. 67 (1932), pp. 287–304.

Lower Cretaceous	Some elements of vertebrate fauna of Timor red clays.
Jurassic	*Strophodus* of red clay of Timor. Radiolaria of Danau formation, Borneo. *Asteroconites*, *Halobia* limestone, Celebes.
Triassic	*Halobia*, *Daonella* in limestones of Rotti, Savu. Radiolaria of Rotti, Savu, Ceram, Celebes.
Permian	Elasmobranch elements in red clay, Timor. A few Radiolaria of Borneo.

The red clay on the Noil Tobee is unconsolidated and is the only unsheared occurrence in the islands. The maximum determined thickness is 3 meters. The writer believes that this clay accumulated throughout the Permian, Triassic, Jurassic, and Cretaceous periods and that the exceedingly slow accumulation characteristic of abyssal deposits has concentrated the remains of vertebrates of several periods in this thin series. The deep-sea deposits of the archipelago as a whole are Permian and Mesozoic in age and it seems likely that collecting by zones would yield faunas characteristic of the several periods.

Molengraaff has pointed out the fact that the known abyssal deposits now on land are in the crests of folded mountains or in the uplifted bottoms of geosynclines. The East Indian outcrops are in the central ranges of Borneo and in scattered islands. No early Tertiary rocks occur over them and unless such rocks were eroded away the abyssal deposits must have been uplifted at the close of the Cretaceous.

Summary.—Part of the red clay on Noil Tobee, Timor, is Permian in age and part is Upper Cretaceous. The red clay accumulated throughout Permian and Mesozoic time. The altered red clay of Borneo and the radiolarian hornstones, limestones, and tuffs of the East Indian Archipelago are Permian to Cretaceous in age. The deep-sea bottom may have been uplifted at the close of the Cretaceous rather than in mid-Tertiary time.

BARATARIA FIELD, JEFFERSON PARISH, LOUISIANA[1]

AL FERRANDO[2] AND H. T. RICHARDSON[2]
Houston, Texas

The Barataria field is 15 miles south of New Orleans in parts of Secs. 15 and 22, T. 15 S., R. 23 E., and Secs. 1 and 2, T. 16 S., R. 23 E., Jefferson Parish, Louisiana.

The California Company's Adam-Ruttley Community No. 1,

[1] Manuscript received, January 10, 1941.

[2] Geologist, The California Company.

located 550 feet from the west bank of Bayou Barataria and 27 feet south of the north line of the John Silver tract in Section 2, Barataria Village, was completed as the discovery well on November 2, 1939, through perforations at 8,204–8,214 feet. On a proration test, the well flowed 936 barrels of 36° gravity oil per day through a $\frac{1}{4}$-inch choke with a gas-oil ratio of 936 to 1 and a tubing pressure of 1,300 pounds. The well had been drilled to the total depth of 12,222 feet and a $9\frac{5}{8}$-inch protection string cemented at 8,486 feet. It was plugged back and the discovery sand tested as a result of favorable indications by electrical survey and side-wall cores.

The structure was found and the discovery well located as a result of a reflection-seismograph survey.

At the present time there are 10 producing wells in the field, 8 completed in the discovery sand at 8,200 feet and 2 completed in a deeper sand at 8,750 feet. One dry hole, limiting the producing area on the west, has been drilled, and subsequent drilling has indicated the discovery well to be on the west flank of the structure.

Both of the producing sands are Miocene in age, and at its total depth of 12,222 feet the discovery well, which is the deepest test drilled to date, was still in the Miocene.

The present producing area is limited on the southeast by a fault downthrown toward the southeast, and the accumulation is controlled by reversal north of this fault. However, the results of the reflection-seismograph survey indicate that the structure will probably be shown to be a faulted, dome-like structure of the deep salt-dome type.

The field is being developed on 20-acre spacing.

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DISCUSSION

FUTURE OF FIELD GEOLOGY[1]

R. DANA RUSSELL[2]
University, Louisiana

In the August number of the *Bulletin*, several of the leading geologists of the profession expressed the opinion that field geology, as a technique for the discovery of oil fields, has not only passed its peak but has practically exhausted its usefulness except in foreign work. Levorsen pointed out that the search for favorable surface structures reached a peak in 1920 to 1925, and since then has "declined to a relatively small proportion of the effort in 1940."[3] DeGolyer[4] seems positive that field geology has become unimportant as a means of finding oil. Lahee[5] also notes the decrease in field work, and decries the resultant lack of adequate field training among the younger geologists—training which is as necessary a background for geologic work in the petroleum industry as in other fields of geology.

The decline in field effort is obvious; we indeed seem to be out of the "stout shoes" period. The writer challenges, however, the conclusion that the usefulness of field geology has been exhausted, and wonders whether the decline may not be ascribed in part to other factors. Although most of the continental United States has been covered by reconnaissance field work, there are still many areas where detailed search for surface structures has not been completed, in fact, has hardly begun. The northern Gulf Coast region—northeast Texas, central and northern Louisiana, southern Arkansas, Mississippi, Alabama, and Florida—is such an area. Throughout this region dips, in general, are very low except on the flanks of piercement-type salt domes. The abnormally high dips on such structures led to their early identification, but the classic method of dip-and-strike mapping failed to reveal the presence of many other structures which have since been proved more productive. These structures are, however, evident from surface investigation when stratigraphic subdivisions of limited thickness, or key beds, are established and carefully mapped. Establishment of such subdivisions may require careful field study and coöperation between field geologist and paleontologist, but once recognized, field mapping is comparatively rapid and easy.

Members of the Louisiana Geological Survey have now mapped, or partially mapped, fifteen parishes (counties) in central and northern Louisiana. Twenty-seven oil and (or) gas fields occur in these parishes. The work of Survey geologists shows that all except three of these (Clayton, Cheneyville, and

[1] Manuscript received, November 9, 1940.

[2] Associate professor of geology, Louisiana State University.

[3] A. I. Levorsen, "Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 8 (August, 1940), pp. 1355–60.

[4] E. DeGolyer, "Future Position of Petroleum Geology in the Oil Industry," *op. cit.*, pp. 1389–99.

[5] Frederic H. Lahee, "Where Will Young Graduates in Petroleum Geology Acquire Field Experience," *op. cit.*, pp. 1386–88.

Eola), which are entirely covered by alluvium, show on the surface and could have been discovered by careful surface mapping. How were they discovered? C. P. Dunbar,[6] after carefully searching the literature and compiling the opinions of recognized authorities, assigns the discovery of fourteen of them to the following methods.

Surface geology—Pleasant Hill, Zwolle
Surface geology plus subsurface work—Cotton Valley, Cartersville-Sarepta, Shongaloo, Tullos-Urania
Surface indications plus geophysics—Driscoll, Sibley
Subsurface work only—Lake Bistineau
Geophysics only—Bear Creek
Subsurface work and random drilling—Logansport
Random or wildcat drilling only—Converse, Desoto-Red River, Holly

In only two can discovery be ascribed to surface geology alone, with surface indications aiding in the discovery of six others. Yet all could have been found by surface mapping.

Of the remaining ten fields, one (Jena) was discovered by geophysics, for seven (Benson, Georgetown, Grogan, Olla, Spider, Sutherlin, and White Sulphur Springs) the writer does not have accurate information on the discovery method, and two (Little Creek and Zenoria) are structures mapped by a member of the Survey.[7] In addition, Survey geologists have found several well developed structures, and numerous less evident prospects, which have not yet been tested. This in spite of the fact that the field work of Survey members is semi-reconnaissance rather than detailed, as the areas to be covered are too large and the time too limited for really detailed work. Were time available for the mapping of smaller stratigraphic divisions, additional structures probably would have been found.

If further proof of the value of field geology in this region is required, one need only consider Mississippi, one of the "hottest" areas in this part of the country. Mississippi has been covered not once, but several times, by geophysical surveys. Yet it remained for F. F. Mellen, doing surface geology on a W.P.A. project, to discover the first oil field in the state.

Why, then, is not field geology more widely used in this region? The writer believes there are two reasons: (1) rough reconnaissance surveys did not reveal the presence of many structures later found by other methods, and the relative failure of reconnaissance methods undermined confidence in surface techniques in this area; (2) the application of geophysical methods to the Gulf Coastal salt-dome region resulted in such phenomenal success that geophysical prospecting became the standard method of exploration for the whole region. The decline in surface geology thus was not due to exhaustion of its possibilities, but to the fact that other techniques became more popular. Detailed field mapping was not developed as it should have been.

The writer is in perfect agreement with the major points in all three of the articles cited. He is particularly gratified by Levorsen's opinion that detailed studies of sediments and sedimentation are likely to be of increasing value in the future, for sedimentation is his major interest. He is also in agreement

[6] C. P. Dunbar, "Oil and Gas Statistics of Louisiana," *Supplement to 14th Bien. Rept., Louisiana State Dept. Conservation* (1940).

[7] H. N. Fisk, "Geology of Grant and La Salle Parishes," *Louisiana Dept. Cons. Geol. Bull. 10* (1938).

with DeGolyer as to the great value of "speculative geology." Lahee's point concerning the necessity of adequate training in field geology has long been recognized by the faculty of the School of Geology at Louisiana State University. This need is now largely filled by the coöperative arrangement between the School of Geology and the Louisiana Geological Survey. Though some of the Survey field work is done by faculty members of the School of Geology, most of it is done by graduate students, and present plans call for graduate students, under adequate supervision, to carry on all field mapping in the future.

The writer's complaint, therefore, is not with the major point in any of the articles, but with the implication that field methods are no longer useful as a means of finding oil except in relatively unknown foreign areas. As DeGolyer points out, surface mapping is by far the cheapest of exploration methods; it should not be abandoned in favor of more expensive techniques until its possibilities have been exhausted. It seems evident that this point has not been reached, at least in the northern Gulf Coast region.

Houston Chamber of Commerce

Statue of General Sam Houston at Hermann Park, Houston. General Houston led the early Texans to victory in the struggle of Texas to obtain independence from Mexico in 1836. General Houston helped establish the new Republic of Texas, and served as its first president.

The twenty-sixth annual meeting of the Association will be held at the Rice Hotel, Houston, April 2, 3, and 4, 1941.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

ANNUAL REVIEWS OF PETROLEUM TECHNOLOGY, VOL. 5, BY THE INSTITUTE OF PETROLEUM

REVIEW BY J. E. BRANTLY[1]
Los Angeles, California

Annual Reviews of Petroleum Technology, Vol. 5 (Covering 1939). Published by The Institute of Petroleum (formerly The Institution of Petroleum Technologists), The University, Edgbaston, Birmingham (1940). Cloth. 444 pp., 6×9 inches. Price, 11 s.

The *Annual Reviews of Petroleum Technology*, 5th Volume, covering 1939, published by the Institute of Petroleum of Birmingham, England, proposes to present a concise résumé of the petroleum industry in its various technical ramifications from the origin of oil to petroleum statistics. Its success in its efforts is quite commendable and the volume is not only presently useful but will preserve a precise record of the knowledge and developments of the industry up to the time of publication.

There are twenty-eight separate subjects or phases of the industry discussed by forty-one different authors within the limits of 444 pages. The subjects discussed include geology and geophysics and drilling and production methods. Transportation and refining are duly considered and many products of the refinery and their uses are discussed. Considerable attention is given to motor fuels and their manufacture and, what seems to be rather unusual in a volume of this nature, though not necessarily out of place, there is a brief treatise on automobile engines, aero engines, and oil engines.

There is likewise consideration of fuels that can be and are being used as substitutes for petroleum products, and lubricants and lubrication are discussed. Finally, Petroleum Literature for 1939 and Statistics are the closing chapters.

Members of A.A.P.G. will be especially interested in "Petroleum Geology," "Regional Exploration and Development in the United States," and "Production Engineering," the authors of which are A. I. Levorsen, W. A. Ver Wiebe, and G. H. Scott, respectively, all members of the Association.

The various subjects are almost without exception creditably presented and will give the reader a hasty view of the various technical problems of the petroleum industry, or rather the results of the solutions of these problems. Some may consider discussions of internal combustion engines and the uses of asphalt as road material to be somewhat out of place, but after all the prosperity and usefulness of the industry depend on the machinery and processes requiring its products. The chapters on competitive or substitute materials are interesting and thought-provoking.

[1] President, Drilling and Exploration Company, Inc. Manuscript received, December 1, 1940.

A fair criticism of the volume from the standpoint of the reader—which, however, is not a criticism of the authors or the Institute—is that the subjects are too briefly handled, but it was quite evidently their intention to refer the reader to more exhaustive treatises on those subjects which he found too meagerly discussed for his purposes.

The efforts of the authors and the Institute are amply justified in the fruits of their labors.

GEOPHYSICAL PROSPECTING FOR OIL, BY L. L. NETTLETON

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

**Geophysical Prospecting for Oil*, by L. L. Nettleton. 444 pp., 6×9 inches, 177 illus. McGraw-Hill Book Company (1940). Price, $5.00. May be ordered from the A.A.P.G., Box 979, Tulsa, Oklahoma.

In the early days of geophysical exploration Dr. Margaret Cobb translated and made available Richard Ambronn's book dealing with the principles and methods involved in this field of activity. However, during the following 14 years that saw radical changes in equipment and technique with the expansion of geophysical exploration to a dominant position in prospecting for oil, there was no comprehensive publication available to explain adequately the methods, use, and value of this very successful and very costly means of oil exploration. Now, in 1940, three treatises by competent authorities appear in close succession, one by Nettleton, who confines his text to geophysical prospecting for oil, the others by Heiland and by Jakosky who treat all uses of geophysical methods. Thus, students, geophysicists, and others interested in the subject who have been getting their information from scattered sources for many years, now have three up-to-date books to consult in reference to this field of activity.

Nettleton's book is an attempt "to supply a source giving a connected presentation of the principles and practices of modern oil prospecting by geophysical methods and is intended mainly for the student and lay reader." It is reviewed from the viewpoint of the lay reader who has had long contact with geophysical activities.

The book is well printed in large type on good paper. The illustrations are clear, but are confined too largely to small line cuts of geometrical problems where the relationship with actual subsurface conditions is not too clearly presented. Section headings and chapter subdivisions are set up boldly.

The subject matter which is inherently technical and involved is handled in a readable and understandable manner in large part. At times it has been necessary to devote numerous successive pages to complicated mathematical formulae which will doubtless entertain the student for many hours, but which interrupt the continuity of the reading for those who are not apt in higher mathematics. The treatment is reasonably condensed into a handy volume of about 450 pages.

After a brief preliminary statement the author plunges into detailed consideration of the different methods. Part I covers Gravitational Methods in

[1] Amerada Petroleum Corporation. Manuscript received, December 5, 1940.

146 pages; Part II, Magnetic Methods in 74 pages; Part III, Seismic Methods in 132 pages; Part IV, Electrical and Other Methods in 56 pages; Part V, Geophysical Interpretation in 10 pages. In each of the first four parts the fundamental principles, the units, the types of instruments, and the calculations are discussed, and an adequate but not exhaustive bibliography is presented. The presentation of gravity instruments and calculations is particularly complete, while the seismic presentation is largely confined to consideration of refraction shooting. Fifteen pages are devoted to reflection shooting, 35 pages to refraction shooting, and 65 pages to gravity instruments. In view of Professor Nettleton's statement that 75 per cent of geophysical crews and 85–90 per cent of the cost of geophysical operations are applied to reflection shooting, more space should have been devoted to clarifying the different applications of this method. Thus, a better balance would have been reached in the presentation of the subject matter covering the several methods.

Geophysical prospecting for oil is actually prospecting for structural features in oil-bearing strata which are known to be favorable to oil accumulation. These features may be anticlines, domes, closures against faults, or any one of a number of structural anomalies which are best represented by a contour map showing the location, shape, and amount of relief of the feature. In order to represent geophysical data in some such fashion it is necessary to translate minute physical anomalies such as local variations in the mass of the earth or in the magnetic field of the earth, or in the travel time of sound waves through the earth, into the size, shape, and amount of uplift of structural irregularities. This translation, known as interpretation of data, is the most vital part of geophysical prospecting for oil. It is the feature on which the major expenditure of oil-company exploration money depends. Therefore, interpretation should occupy a prominent place in any book covering the subject of geophysical prospecting. Actually, this book touches on it only briefly at several points, with the final Part V devoting most of its 10 pages to a generalized discussion of interpretation by geologists *versus* physicists.

Finally, a fair analysis of the value and usefulness of each method should have been included in a summary with some reference to the areas covered and discoveries that have resulted from the use of each.

I feel that Professor Nettleton has compiled a useful abridged volume on geophysical methods, but he has failed to cover the whole field of geophysical prospecting for oil adequately, principally through failure to accord deserved attention to interpretation of data.

LOWER CRETACEOUS AND JURASSIC FORMATIONS OF SOUTHERN ARKANSAS, BY RALPH W. IMLAY

REVIEW BY W. S. ADKINS[1]
Houston, Texas

"Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities," by Ralph W. Imlay. *Arkansas Geol. Survey Inform. Cir. 12* (Little Rock, July 30, 1940). viii+64 pp., including 10 tables, 26 plates of maps and cross sections, with bibliography. Price, $1.25 plus $0.15 postage.

[1] Shell Oil Company, Inc. Manuscript received, December 4, 1940.

This bulletin contains an excellent and up-to-date summary of the subsurface Lower Cretaceous and Jurassic geology of southern Arkansas and adjacent areas, especially northern Louisiana. Rocks younger than the Lower Cretaceous are not treated in the report. Throughout this area there is a large unconformity at the Upper-Lower Cretaceous boundary. The Lower Cretaceous rocks have been tilted generally to the southwest and beveled, so that the strike of their pre-Upper Cretaceous outcrops as seen on a paleogeologic map is northwest-southeast; and their aggregate remaining thickness decreases in a northeastward direction. Likewise the Upper Cretaceous thins in the same direction by progressive overlap of the lower beds by successively younger beds on the beveled surface of the Comanche. At the outcrop, the remaining equivalents of the formations treated in this bulletin are much reduced: (a) the Washita beds are missing at the outcrop; (b) the Fredericksburg is represented by thin Kiamichi shell-marl and by thin underlying Goodland, a shelly limestone containing *Requienia*, *Toucasia*, and other Edwards-like fossils, exposed just north of Cerrogordo, in southwesternmost Arkansas; (c) the underlying Trinity ranges in thickness from 1,000 feet in southwest Arkansas to nothing farther east, and consists of red and varicolored clays, and sands, with thin members of gravel, shelly limestone, and gypsum. These rocks pass south and west underground into the 13,500-foot basin section described in this report.

The discovery of such an extensive section unknown at the outcrop resulted from well drilling subsequent to 1932.[2] Among the earliest wells drilled below the "Lower Red Beds" or "Travis Peak" were the Humble Oil and Refining Company's Bliss and Wetherbee No. 30, Bellevue field, Bossier Parish, Louisiana, which penetrated the upper 330 feet of the Cotton Valley fossiliferous shales; H. I. Morgan's Smith No. 2 in the same field, which penetrated about 1,400 feet of the Cotton Valley; and the Dixie Oil Company's Dillon wells, Pine Island field. Since none of these subsurface units could be referred to the Arkansas outcrop nomenclature, the earliest system of dealing with them was to refer them to the central Texas outcrop formations. However, this outcrop section is likewise thin and transgressively overlaps upon a beveled surface, so that it is insufficient as a standard of reference. In reality, the most comparable section is that exposed in the north Mexican geosyncline in the states of Coahuila and Chihuahua, but the remoteness of this area forbids transfer of its local units to the Louisiana-Arkansas area. The correct solution is that which is so excellently set forth by the author: recognize subsurface stratigraphic units, each with its subsurface type locality; set up a new standard section; and correlate this with Coahuila-Chihuahua and with other pertinent areas. In this enterprise he made full use of the work which has been done by geologists in the area, including Roy T. Hazzard, Warren B. Weeks, and several others, who had largely assembled the facts presented in this report. As stated in the preface, the author availed himself of a consensus of geologists on the subdivision and naming of the stratigraphic units; the formation names used are believed to be unpreoccupied; the depths and other well data used were checked from company records. Since now a standard subsurface section has been set up in Arkansas-Louisiana, geologists working

[2] Reviewed by A. F. Crider, "Pine Island Oil Field, Caddo Parish, Louisiana," *Guide Book of Shreveport Geological Society Fourteenth Annual Field Trip* (1939), pp. 6–10.

on the Texas subsurface may experience the aforementioned difficulty in reverse, namely, that some of their units can not be referred with certainty to those presented in this bulletin.

Subsurface formations used in this report, in descending order, are as follows. In the Lower Cretaceous, the lower Washita, Kiamichi, Goodland, and Walnut are somewhat as at the outcrop. Paluxy, the old "Upper (Trinity) Red Beds," interfingers into a marl-limestone section south of Shreveport, and contains practically no oölitic limestones. [ab]Mooringsport[3] (limestones, shales), the old "Upper Glen Rose," contains the upper anhydrite stringers. [ab]Ferry Lake (anhydrite) is the former "Middle Glen Rose" main anhydrite. [a]Rodessa (limestones, shales), with the next two units named, makes up the old "Lower Glen Rose." [a]Pine Island (shales, limestones) is a principal ammonite-bearing unit, containing *Dufrenoya* and other fossils. [ab]Sligo (gray to brown shale, with lenses of limestone and sandstone), the old basal "Glen Rose," includes the Pettit porous limestone zone. [b]Hosston (red shales, sands, limestones) is the old "Lower Red Beds" or "Travis Peak." Imlay has established, below the Trinity group, a basal Lower Cretaceous unit, the "Coahuila group," which includes all formations from the top of the Hosston to the base of the Cretaceous.

Upper Jurassic units in descending order are: [a]Cotton Valley (fossiliferous shales and limestones on the south, interfingering northward in southern Arkansas and northeasternmost Louisiana into Schuler redbed facies containing prominent siderite pellets) at its base is transgressive on the Buckner, Smackover, and Eagle Mills units. The possibility of basalmost Cretaceous age of the Cotton Valley has not been excluded. [a]Buckner (including anhydrite) in position is suggestive of the gypsum at Malone Mountain, Hudspeth County, Texas; Burckhardt has reported gypsums in northeastern Mexico in both Kimmeridgian and Portlandian. [a]Smackover (limestones) consists of upper oölitic to chalky, fossiliferous limestones, and lower dense, laminated, less fossiliferous limestones with dark argillaceous bands. Lithology similar to this and to the Buckner occurs in the Stanolind Oil and Gas Company's Norris No. 1, Limestone County, Texas. [a]Eagle Mills (salt, redbeds) in position suggests salt occurrences in southern Mexico, Chinameca, and Tehuacan areas. [ab]Morehouse (shale containing fossils) is known from one well, the Union Producing Company's Tensas Delta No. 1-A, Morehouse Parish, Louisiana, the type locality.

A mass of detail on the Upper Jurassic and Lower Cretaceous of north-central Mexico is contained in publications by Böse, Burckhardt, Burrows, Prescott, Imlay, and others, and in many unpublished materials such as the study by Ransome on the Cretaceous of Los Lamentos, Chihuahua (the fossils are at Tucson); exploration by R. E. King and the reviewer of the fine ammonite sequence, Kimmeridigian to Tithonian[4] and basal Cretaceous to Eagle Ford in the Cuchillo Parado-Placer de Guadalupe-Los Fresnos area, northeast Chihuahua; the extensive ammonite sequence from near Sierra Mojada sent by Wingfield to the reviewer, and other materials. These show ammonite zones extending from the Oxfordian to the top of the Jurassic, and above them

[3] [a] Exclusively or largely subsurface units. [b] New in this report.

[4] Based on zonation by L. F. Spath, "Revision of the Jurassic Cephalopod Fauna of Kachh (Cutch)," *Paleon. Indica*, N. S., Vol. 9, Pt. 6 (1933).

a full sequence of Lower Cretaceous. In the Conchos Valley section, the Cuchillo formation, containing clay, gypsum, *Douvilleiceras* above, and *Dufrenoya* below, strikingly suggests the "Glen Rose" sequence in Louisiana (Ferry Lake anhydrite, Pine Island with *Dufrenoya* and other ammonites); and the underlying Las Vigas is suggestive of the Hosston (see Imaly, Table 3).

The evidence and suggestions of probable Jurassic age are in part as follows. Imlay considers the Cotton Valley to be uppermost Jurassic, that is, Tithonian-Portlandian, an age suggested by the presence of *Pseudomonotis* and *Tancredia*.

In the Smackover: *Coelopis* and *Quenstedtia* not recorded in beds younger than Jurassic; *Coelastarte*, fairly common in Jurassic, uncommon in Cretaceous. The association of *Xystrella?* and *Cryptotaxis?*, if correctly identified, indicates "lower Upper Jurassic." Dr. Spath was unable to state whether the incompletely preserved ammonites found in The Texas Company's Adams No. 1, Bethany field, Panola County, Texas, are Jurassic or Cretaceous.

In the Morehouse formation: sponge probably of the family Staurodermidae, "which is known only from the Jurassic"; some small pyritized *Corbula*-like pelecypods are common in the same cores from the Union Producing Company's Tensas Delta No. 1-A, Morehouse Parish, Louisiana.

The few facts or suggestions of age assignment at hand seem to refer the Morehouse to Cotton Valley, inclusive, to the Upper Jurassic (Oxfordian-Tithonian)—ages which are possible regionally and in comparison with the Mexican section, but further evidence, particularly from ammonites, is urgently needed.

The study of the detailed subsurface stratigraphy of this area is still not very far advanced, so that much remains to be done on facies changes, paleontology, zonation, and correlation. At present, widespread lithologic breaks are taken as bases of correlation; electrical logs, generally usable in this area, provide an accessory to this type of correlation. However, it can not be assumed without proof that lithologic breaks give the chronologic correlation even if apparently supported by some kinds of fossils; lithology, fossil zones or at least teil-zones, and contemporaneity need not coincide with each other.[5] Certain megafossils show the features of markers: they seem to parallel the lithology, to have wide horizontal and restricted vertical range, and are recognizable. Microfossils of the Lower Cretaceous in this area have been only slightly investigated, but some studies are being made on the microfaunas of the Cotton Valley and other units. Much work remains to be done on the megafossils, especially the ammonites. Many cores from Cotton Valley, Smackover, and other units contain numerous megafossils, including pelecypods (some suggestive of the Malone Jurassic), gastropods, and a few corals, crustaceans, and rare ammonites. Many valuable fossils from this area have been lost or dispersed. Every effort should be made to save fossils and to have them determined; the reviewer takes the liberty of urging that anyone who obtains such fossils advise Roy T. Hazzard, Gulf Refining Company, Shreveport, Louisiana, or the reviewer, and, if possible, send the cores or fossils so that we may arrange to have them identified.

A few minor points might be noted. Plate I might have included additional structural features, such as the Bienville syncline, the South Missis-

[5] Cf. L. Dudley Stamp, *Geol. Mag.*, Vol. 62 (1925), pp. 515–28.

sippi (Mobile) platform. Connection of Ouachita geosyncline with Jackson dome would be rated as speculative. Plate XXV shows Puerto Rico as land in Fredericksburg time, but Bela Hubbard described Edwards fossils from there. Further ammonite collections from central Texas will be necessary to decide whether Pine Island equals lower Glen Rose, as shown in Table 3, rather than Travis Peak. Page 28: *Dufrenoya* is not confined to upper Aptian in Europe (L. F. Spath, *Ann. Mag. Nat. Hist.*, Ser. 10, Vol. 5 (1930), pp. 417–64, and perhaps not to the Travis Peak in Texas (Scott, *Univ. Texas Bull. 3945* (1940), p. 1027).

DIE BODENSCHÄTZE BOLIVIENS, BY FRIEDRICH AHLFELD AND JORGE MUÑOZ REYES

REVIEW BY JOHN L. RICH[1]
Cincinnati, Ohio

Die Bodenschätze Boliviens (The Mineral Resources of Bolivia), by Friedrich Ahlfeld and Jorge Muñoz Reyes. 199 pp. with 65 maps and figures and a map of the mineral deposits of Bolivia on a scale of 1:1,500,000. Gebrüder Borntraeger, Berlin (1939). Price, RM28.

The book is devoted mainly to a detailed account of the mineral deposits of Bolivia, arranged primarily according to the geologic age of the deposits and secondarily according to the various minerals and ores in the general order of their importance.

For the petroleum geologist, the features of most interest are the introductory general sections on "Morphology," "Geological Formations," and "Tectonics"—only 11 pages altogether, including a table entitled "Geological History of the Bolivian Andes"—plus the 17 pages contributed by Reyes, dealing with the petroleum resources.

The part of Bolivia that holds most promise of containing important oil deposits is a belt of openly folded Paleozoic, Mesozoic, and Tertiary rocks along the eastern base of the Andes. The authors divide the belt into three sections: a southern section, about 330 miles long, from the Argentine border to Santa Cruz; a central section northeast of Cochabamba; and a northern section about 150 miles long in the province of Caupolican extending northwestward to the Peruvian border.

The southern section is fairly well explored geologically. It has many oil seepages and 29 test wells have been drilled, of which 13 were productive. Many structurally and stratigraphically favorable localities in this zone have not yet been tested. The oil is found in rocks of various ages from Lower Devonian to Tertiary but the author thinks that the principal source is the thick series of dark, bituminous shales of the Lower Devonian.

In the central zone, northeast of Cochabamba, a great border fault separates a very thick section of strongly disturbed Lower Devonian of the Cordillera from terrestrial Mesozoic rocks east of the mountains. In the latter, at least one large anticline has been recognized, striking generally parallel with the Andean front, but the region is difficult of access and has not been adequately explored. No oil seepages have been found and no drilling has been done.

[1] University of Cincinnati. Manuscript received, January 14, 1941.

In the northern section, in the province of Caupolican, the land sinks gradually from the eastern Cordillera of the Andes to the lowlands of the Rio Beni. In the western part of this slope the Paleozoic rocks are at the surface. They show weak folding with northwest strike and little faulting, but are strongly metamorphosed. Overlying the Paleozoic on an inconspicuous unconformity is a series comprising about 3,300 feet of Jurassic-Cretaceous marls and sandstones gently folded into northwest-striking anticlines and synclines with prevailingly moderate dips, few of which are as steep as 50°. Several seepages of high-grade oil are known where streams cross the anticlines. Because of the size of the region, the large number of anticlines, and the simple tectonics, the author considers this the most promising part of Bolivia for oil reserves. As the region is very difficult of access, it has been little explored and is entirely untested.

On the Andean highland, from Cochabamba southeast to Mizque, the Lower Devonian sediments are relatively little disturbed and show asphalt in places. Some have thought that this region is promising, but the author does not share that view. He thinks that the rocks are too much broken and have suffered too much metamorphism.

An oil seepage along the Arica-La Paz railway, a short distance east of the Bolivian border, is also considered to have little possible commercial significance. It occurs in a series of tuffs and related volcanic clastics of Miocene age.

Those interested in the other mineral resources of Bolivia will find in *Economic Geology*, Vol. 35 (1940), pp. 110–17, a full review by J. T. Singewald, Jr.

RECENT PUBLICATIONS

GENERAL

*"The Theory of Ground-Water Motion," by M. King Hubbert. *Jour. Geol.*, Vol. 48, No. 8, Pt. I (Chicago, Illinois, November–December, 1940), pp. 785–944; 48 figs.

*"Northern Hemisphere Offers Greater Oil Possibilities," by W. V. Howard. *Oil and Gas Jour.*, Vol. 39, No. 35 (Tulsa, January 9, 1941), pp. 14–15; 26; 2 figs.

*"Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain. Part IV. Cape May, New Jersey, Section," by Maurice Ewing, George P. Woollard, and A. C. Vine. *Bull. Geol. Soc. America*, Vol. 51, No. 12, Pt. 1 (New York, December 1, 1940), pp. 1821–40; 6 pls., 3 figs.

*"Abstracts of The Geological Society of America December Meeting at Austin." *Bull. Geol. Soc. America*, Vol. 51, No. 12, Pt. 2 (December 1, 1940), pp. 1919–54.

**Ibid.*, "Cordilleran Section Meeting at Los Angeles in April," pp. 1955–66.

*"Abstracts of the Paleontological Society December Meeting at Austin," *ibid.*, pp. 1967–80.

**Ibid.*, "Pacific Coast Branch Meeting at Los Angeles in April," pp. 1981–88.

*"Abstracts of Section E, American Association for the Advancement of Science December Meeting at Philadelphia," *ibid.*, pp. 1989–2014.

**Ibid.*, "June Meeting at Seattle," pp. 2015–38.

**Ibid.*, "Papers Presented at Columbus (1939) Meeting but not previously published," pp. 2039–42.

Selected Bibliography of the Theories of the Origin of Petroleum, compiled by Alan G. Skelton and Martha B. Skelton. 12 pp., mimeographed. Published by the Oklahoma Geological Survey, Norman, Oklahoma. Price, 3¢ stamp.

GERMANY

*"Rumanian Petroleum Prospects," by Karl Krejci-Graf. *Oel und Kohle*, Vol. 36, No. 40 (Berlin, October 22, 1940), pp. 386–89; 3 figs. In German.

*"Prospective Petroleum Regions in Jugoslavia," by L. Sommermeier. *Ibid.*, pp. 406–14; 4 figs., 1 folded map.

*"Petroleum Occurrences of Murinsel (Jugoslavia)," by Egon Böhm. *Ibid.*, pp. 415–22; 12 figs., 5 tables.

*"Petroleum Geological Investigations in Western Hungary (Transdanube) and the Oil Fields of Lispe," by R. von Zwerger. *Ibid.*, pp. 425–37; 3 figs., 1 table.

*"Petroleum Possibilities in Bulgaria," by O. Barsch. *Ibid.*, pp. 438–43; 1 fig.

*"The Prospective Oil Region of Western Thrace (Greece)," by E. Wirth. *Ibid.*, pp. 443–56; 13 figs.

ILLINOIS

"Preliminary Geologic Map of Parts of the Alto Pass, Jonesboro, and Thebes Quadrangles," by J. Marvin Weller and George E. Ekblaw; "Explanation and Stratigraphic Summary," by J. Marvin Weller. *Illinois Geol. Survey Div. Rept. Investig. 70* (Urbana, January 3, 1941). 26 pp., 1 pl., 2 figs.

JAPAN

*"Micropalaeontological Studies of Drill Cores from a Deep Well in Kita-Daito-Zima (North Borodino Island)," by Shôshirô Hanzawa. *Jubilee Publication in the Commemoration of Professor H. Yabe's 60th Birthday* (Inst. Geol. and Paleon., Tôhoku Imperial University, Sendai, 1940), pp. 755–802; Pls. 39–42; Figs. 1–5.

MISSISSIPPI

*"Lauderdale County Mineral Resources." Geology by V. M. Foster. Tests by Thomas Edwin McCutcheon. *Mississippi Geol. Survey Bull. 41* (University, Mississippi, 1940). 246 pp., 23 figs., 1 pl.

SOUTH DAKOTA

"A Magnetic Survey of Central South Dakota," by W. H. Jordan and E. P. Rothrock. *South Dakota Geol. Survey Rept. Investig. 37* (Vermillion, November, 1940). 35 pp., 5 figs., 1 map.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 10, No. 3 (December, 1940).

"The Relative Resistance to Abrasion of Mineral Grains of Sand Size," by George A. Thiel

"Heavy Mineral Associations in Quaternary and Late Tertiary Sediments of the Gulf Coast of Louisiana and Texas," by Max Bornhauser
"Tremolite Bearing Limestone of the Capitan Quadrangle, New Mexico," by Leroy T. Patton
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**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 15, No. 1 (January, 1941).

"Cenozoic Regular Echinoids of Eastern United States," by C. Wythe Cooke
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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 2 (FEBRUARY, 1941), P. 337

RESEARCH NOTES

RESEARCH COMMITTEE CONFERENCES

The research committee plans to continue at the Houston meeting of the Association the conferences which were commenced last year at the Chicago meeting. These conferences are scheduled from 2:00 to 5:00 P.M., Tuesday afternoon, April 1, the day preceding the opening of the regular technical program of the convention. Rooms have been set aside in the Rice Hotel at Houston for the use of the various conference groups and all interested in taking part in the discussions are invited to attend.

The subjects to be discussed are some of the fundamental problems of petroleum geology and will be a continuation of the informal discussions held last year.The subject of the conferences and the respective leaders are as follows.

SEDIMENTATION

Leader: Wayne Galliher, Barnsdall Oil Company, Petroleum Securities Building, Los Angeles, California

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Assistant leader: Ben H. Parker, Colorado School of Mines, Golden, Colorado

A mimeographed résumé of the proceedings of the Chicago meetings together with the program of the Houston meeting is available to anyone writing to the leaders of the respective conferences.

A. I. LEVORSEN
Chairman, research committee

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 2 (FEBRUARY, 1941), PP. 338-345, 1 FIG.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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TWENTY-SIXTH ANNUAL MEETING, HOUSTON, APRIL 2–4, 1941

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ANNOUNCEMENT—INVITATION

The twenty-sixth annual meeting of the Association will be held at the Rice Hotel in Houston, Texas, April 2, 3, and 4, 1941. The Houston Geological Society cordially invites the members of the Association, their wives and friends.

The fifteenth annual meeting of the Society of Economic Paleontologists and Mineralogists will be held on April 2, 3, and 4. The Society of Exploration Geophysicists will hold its eleventh annual meeting on April 1, 2, and 3. Both meetings will be at the Rice Hotel. Both societies are invited to attend the Association meetings, as well as the dance and other features.

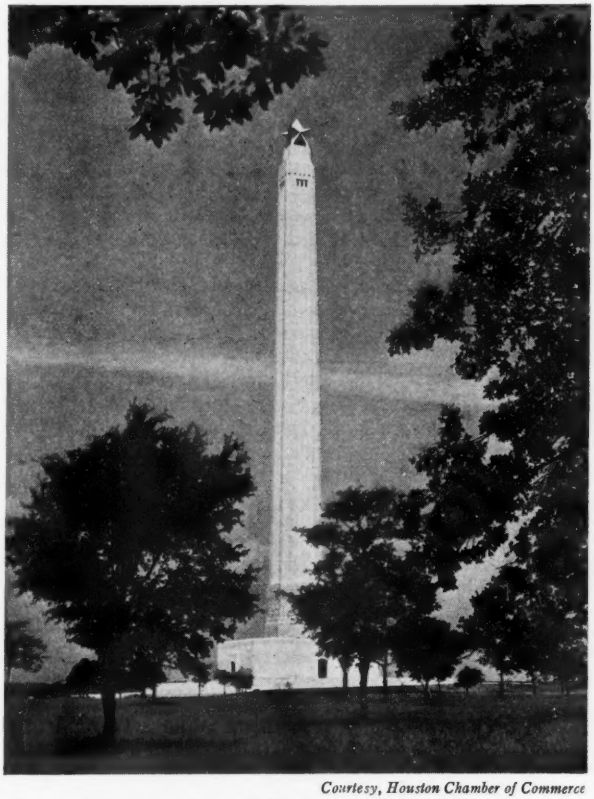
PRE-CONVENTION SESSIONS

The S.E.G. will begin holding regular technical sessions on Tuesday, April 1, while the A.A.P.G. committees on Business, Applications of Geology, Research Groups and Publications will meet the same day.

Of special interest to members attending the pre-convention sessions will be the Research Dinner and Round-Table Discussion to be held Tuesday evening. The subject of the Round-Table discussion will be "Possible Future Oil Provinces in the United States and Canada." This discussion will be held under the chairmanship of A. I. Levorsen, who promises a very profitable evening with short résumés on these provinces by authorities.

REGISTRATION

Members and guests are urged to register as soon as possible after securing hotel accommodations. The registration counter will be in the Lounge, Second Floor, Rice Hotel, and will be open from Monday noon until the conclusion of the meetings. There will be no registration fee.



Courtesy, Houston Chamber of Commerce

San Jacinto memorial shaft at San Jacinto battleground, near Houston, marking spot where the Texas army under General Sam Houston defeated the Mexican army under Santa Ana, thus winning for Texas her independence. This structure is 567 feet high, 12 feet higher than the Washington Monument.

SCIENTIFIC EXHIBITS

Paul Weaver, chairman of this committee, has spent considerable time, money, and effort in order to make these exhibits outstanding. His recent exhibit for the G.S.A. in Austin was very favorably commented upon by all who were fortunate enough to see it. In addition, several of the universities will have private exhibits, most of which have not heretofore been shown.

UNIVERSITY REUNIONS

Luncheons and dinners for university groups can be arranged upon request. Please contact the reception committee (Carleton D. Speed, chairman), as soon as possible so that space will be reserved. These arrangements should be made prior to arrival.

FIELD TRIPS

Houston is unique in the variety of field trips which can be offered from this city. There is the salt mine, where one can be lowered more than 1,500 feet down a shaft and see huge chambers flanked by walls of salt; there are the sulphur vats and tanks where liquid sulphur is cooled, solidified, and stored; there are the mounds one unexpectedly encounters in an otherwise featureless plain which express topographically the intrusions of salt masses; there is the drilling in bays and the Gulf of Mexico where specially designed water equipment is used; there are the paraffine-dirt beds, the sour-water lakes, and the gas seepages which led the first geologists to vast reserves of oil; there is the subsidence in the earth surface due to withdrawals of oil, sulphur, and salt water which formed underground caverns in the salt and dome material.

In addition to the points of geologic interest, Houston has several points of historical interest to Texans and the Southwest. The San Jacinto Battlefield, where Texas won its independence from Mexico in 1836, is almost within the city limits. At this spot there has been erected a monument 570 feet in height with a museum of Texas history in its base. Likewise, Galveston bay and beach, both of which have played important roles in Texas history, are near by. The beach is one of the finest laboratories known for the study of beach deposits. This island was formerly used by Jean LaFitte as his center of operations during the days of piratical raids.

TECHNICAL PROGRAM

This year the regular order of the program will be slightly changed. Instead of having the joint sessions of the A.A.P.G., S.E.G., and S.E.P.M. with the presidential addresses on Wednesday, these will be held on Thursday and the regular technical sessions will be held Wednesday and Friday. For the joint meetings several prominent men in the industry have been asked to address the meeting after the presidential addresses. General papers on sedimentation, economic importance of various crude oils, and surface geology have been secured to be given by well known authorities in these fields of endeavor. Development papers will be read immediately preceding the technical papers on the district.

GOLF

The golf committee has arranged for luncheon and tournament at one of the country clubs on Friday, so bring your clubs with you. The Bostick Cup is at stake.

LADIES

And as for the ladies, we have just the thing: a style show. Don't you geologists keep your wives home on this account. Styles are better and cheaper in Houston than anywhere in the World. That is, the Texas World. And music for the style show and luncheon by George Olson!

We almost forgot to mention the garden tours and dance. The garden tour can't be surpassed in the United States. The Garden Club of America selected Houston two years in succession in which to hold its convention because of the beauty of the Houston gardens—azaleas and camellias will be

in full bloom. Of course the dance is an occasion in itself. We need not mention that, but the same George Olson will play. For the music lovers, the St. Louis Symphony Orchestra under the direction of Vladimir Golschmann will play at the Music Hall on the night of April 1 (reservations should be made *immediately* with Mrs. Edna W. Saunders, c/o Levy Brothers, Houston, Texas).

HOTELS

A total of 1,550 first-class rooms have been reserved in Houston hotels in, and easily accessible to, the headquarters. Prices range from $2.00 to $4.00 per day single and $4.00 to $6.00 per day double. A large number of twin bedrooms at $4.00 to $6.00 per day and two- and three-room suites from $6.00 per day upward are available.

Reservations should be made with the hotel direct, advising the type and price of room desired and the date of arrival. Confirmation of this reservation should be requested.

It is urged that reservations be made as early as possible as the hotel managements will not agree to hold any of the 1,550 rooms allotted to this convention beyond March 20. Reservations requested after March 20 will have no priority over regular guests. The hotels are prepared to handle registrations promptly on arrival; but if pre-arrival hotel registration and room assignment are desired, a request for such registration should be sent to Olin G. Bell, chairman, Hotel Committee, P.O. Box 2180, Houston, Texas, together with your check of draft for deposit of $10.00. The hotel, type, and price of room desired, and the date and hour of arrival should be mentioned. In case such arrangements are made the guest should immediately upon arrival report to the A.A.P.G. registration booth, Lounge, Second Floor, Rice Hotel, and present his confirmation of registration, where room keys will be furnished direct by the committee in these pre-registration instances.

A special rate is available to *STUDENTS* only at the Rice Hotel. Groups of four to six students will be housed in large rooms equipped with individual beds and all modern conveniences at a cost of $1.25 per person provided that college department heads organizing these groups advise Olin G. Bell, P.O. Box 2180, Houston, Texas, before March 28, giving names and date of arrival of all students so that the proper number of rooms may be assigned.

HOTELS AND MINIMUM RATES

Hotel	*Rooms*	*Blocks from Rice*	*Without Bath*		*With Bath*	
			Single	*Double*	*Single*	*Double*
Rice	1,000	—	—	—	$2.50	$4.00
Wm. Penn	175	5			2.50	4.00
Warwick	153	51			2.50	4.00
Auditorium	175	2			2.50	4.00
Lamar	500	5			2.50	4.00
Texas State	400	3			2.50	4.00
San Jacinto	300	3	$1.50	$2.50	2.50	4.00
Ben Milam	250	6			2.50	4.00
Sam Houston	200	3			2.50	4.00
Cotton	175	3			2.50	4.00
Plaza	102	51			2.50	4.00
DeGeorge	150	6	2.00	3.00	2.50	4.00

TRANSPORTATION

There is no special convention rate in effect on the railroads. You should see your local ticket agent about any seasonal or regional round-trip excursion rates that may be available.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25 NO. 2 (FEBRUARY, 1941) PP. 346-348

Memorial

THOMAS MANN PRETTYMAN

(1888–1940)

On November 2, 1940, Thomas Mann Prettyman died suddenly of a cerebral hemorrhage at his home, 4841 Crestline Road, Fort Worth, Texas.

He is survived by his widow, Caroline Moreland Prettyman, two brothers, Frank and Cannon Prettyman of Summerville, South Carolina; and a sister, Mrs. Virginia Rhett of Charleston, South Carolina.

Mr. Prettyman was born in Cartersville, Virginia, on July 14, 1888. He attended the Virginia Military Institute from September, 1905, to June, 1908. Having decided on a business career, he enrolled at Eastman Business College, Poughkeepsie, New York, and studied there from September, 1908, to May, 1909. For several years thereafter, he was associated with his family in the lumber business in South Carolina. In 1916, he answered the call of the West and came to Texas where he attended the Texas School of Mines at El Paso. He received his E.M. degree from that institution in June, 1918.

During the World War No. 1, he served in the chemical and metallurgical branches of the Ordnance Department, spending most of that time in Pittsburgh and Washington.

After the war, he returned to Texas and worked as assistant geologist with the Bureau of Economic Geology at Austin. He was assigned to work on the oil possibilities of University Lands in West Texas under Dr. Udden and was co-author, with R. A. Liddle, of University of Texas *Bulletin* on the "Geology of Crockett County, with Notes on the Stratigraphy, Structure and Oil Prospects of the Central Pecos Valley." It was this bulletin, published in 1918, which, in a large measure, was responsible for the development of what is now known as the West Texas Permian basin, one of the largest producing areas in the United States.

From February, 1921, to February, 1923, Mr. Prettyman was assistant State geologist of Georgia. His work on the Georgia Survey is summarized in *Bulletin 40*, "Petroleum and Natural Gas Possibilities of Georgia," by T. M. Prettyman and H. S. Cave, published in 1923.

He again returned to Texas, early in 1923, this time as geologist for The Texas Company. During the Mexia-Powell fault-line "play," his work in this region combined with his high technical skill, made him one of the best informed geologists on the "fault line." In 1924, after the discovery of the Big Lake field on University Lands in Reagan County, West Texas became very active and on account of Mr. Prettyman's knowledge of this vast area, he was transferred by The Texas Company to their West Texas division with headquarters at Cisco. He continued his work in West Texas with this company until the partnership of Renaud and Prettyman, consulting geologists, was formed in 1925. This firm maintained offices in Cisco and Abilene and was active until 1929.

In 1929, the firm of Renaud and Prettyman organized the Westexas Oil and Royalty Corporation and moved to Fort Worth. Mr. Prettyman was

vice-president and a director of the company from the beginning and was very active in its affairs until the time of his death.

Prettyman joined the Association in 1924, being sponsored by R. F. Baker, Wallace E. Pratt, and Fred C. Sealey. He was a member of the American Institute of Mining and Metallurgical Engineers, the American Petroleum Institute, the Fort Worth Club, the River Crest Club, the Fort Worth Boat Club, and Sigma Gamma Epsilon.

"Tom" Prettyman's passing was untimely and sudden. He leaves a host of friends who, with affection, will long remember his considerate, friendly, and noble nature.

C. L. RENAUD

FORT WORTH, TEXAS
December 9, 1940

THURMAN H. MYERS
(1890–1940)

On Monday, December 9, 1940, Thurman H. Myers died at his home, 1364 North Sheridan Avenue, Pittsburgh, Pennsylvania, after an illness of 6 months. The cause of death was cancer of the pancreas. Burial was in Wellsboro, Pennsylvania.

Mr. Myers was born in Littleton, West Virginia, November 16, 1890. The advantages of formal college training were denied him, but his interest in the science of geology was such an all-consuming passion that at no time did he allow this handicap to deter him from perfecting his knowledge and abilities in the practice of the art. This he achieved to a degree which earned for him the universal respect and admiration of his professional associates.

During the 5 years from 1910 to 1915, Mr. Myers found employment first as a chainman, later as a full-fledged surveyor and finally as engineer in charge of Highway Construction in various counties in western West Virginia. This work brought him into contact with both coal and oil operators in this part of the Appalachian district. In the short space of 5 years he had sufficiently distinguished himself that in 1915 he was employed as field engineer by the Chalmers Oil Company of Baltimore, Maryland, in connection with the development of their West Virginia properties. A year later he accepted a position as engineer with the Pittsburgh Engineering and Construction Company and within a few months of that time moved on to the grade of mining engineer with the consulting firm of Harrop, Hopkins, and Taylor of Pittsburgh, Pennsylvania.

While his labors in the fields of construction engineering and mining engineering had not been without interest for him, as was attested by his well recognized proficiency, his foremost interest was in geology and by 1917 his knowledge was sufficiently advanced that he was employed by the Benedum and Trees Oil Company of Pittsburgh, to conduct explorations for them in the island of Cuba. In the year following the conclusion of this assignment, he was employed as general superintendent and geologist for the Carter Oil Company, a local corporation operating in Kentucky and Tennessee. Three years later he accepted a similar position with the First Caldwell Oil Corporation in the same area. In 1923, Mr. Myers severed his corporate connections to engage in private practice as a consulting geologist. This was, however, a period of de-

clining activity in the Tennessee-Kentucky area and from 1924 to 1926 he returned to his former field of work serving as resident highway engineer for the Kentucky State Highway Department.

Not for long, however, could "T.H." stay away from his chosen field. In 1926 he became general superintendent and geologist for the Llano Oil Company in Texas and followed this, in 1928, with 2 years of consulting work in West Texas. In 1930 he returned to the Appalachian district as engineer for the Columbia Gas and Electric Company on special work in New York and Pennsylvania. At the conclusion of this project in 1931, he became associated with the Penn-United Gas Company of Pennsylvania as chief geologist and engineer. Four years later he accepted a similar position with the Carnegie Natural Gas Company in Pittsburgh, Pennsylvania, which position he held with distinction at the time of his death.

Mr. Myers was secretary and treasurer of the Appalachian Geological Society, Charleston, West Virginia; vice-chairman of the Oil and Gas Section of the Engineers Society of Western Pennsylvania, Pittsburgh; vice-chairman of the Eastern Production Division of the American Petroleum Institute; a member of the American Institute of Mining and Metallurgical Engineers and of the American Association for the Advancement of Science in addition to his active membership in the American Association of Petroleum Geologists. His publications included "Past Developments and Future Possibilities of the Oriskany Sand in the Appalachian Area," which was included in the Appalachian Geological Society's *Oriskany Sand Symposium*, issued in 1937, and, as co-author with S. H. Cathcart, *Bulletin 107* of the Pennsylvania Geological Survey, "Gas in Tioga County, Pennsylvania."

The geologists and operators of the Appalachian region will sorely miss this man. His warm friendliness, boundless enthusiasm, thoroughgoing honesty and rugged ability were an inspiration to every one of his associates.

M. G. GULLEY

PITTSBURGH, PENNSYLVANIA
January 3, 1941

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 2 (FEBRUARY, 1941), PP. 349-352

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

H. A. STEWART, of The Texas Company, spoke before the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, on "The Oil Country in Northern South America," January 6.

CLELAND N. CONWELL, of Idaho Springs, Colorado, has accepted a position with the United States Vanadium Corporation, Bishop, California.

LOREN I. BUCK has opened an office as consulting geologist in Wichita, Kansas. His address is 338 North Parkwood Lane.

The following officers have been elected in the Oklahoma City Geological Society: president, JOHN E. VAN DALL, Magnolia Petroleum Company; vice-president, CLYDE H. DORR, consulting geologist; secretary-treasurer, GRAYDON H. LAUGHBAUM, Sinclair Prairie Oil Company.

HEATH M. ROBINSON, geologist, announces removal of his office from 1406 Gulf States Building to 1005 Gulf States Building, Dallas, Texas.

L. O. SEAMAN, of the Sinclair Prairie Oil Company, has changed his address from Fort Worth, Texas, to Tulsa, Oklahoma.

VINCENT EVANS has moved from Bismarck, North Dakota, to Tuscaloosa, Alabama.

SPENCE T. TAYLOR, of the Tide Water Associated Oil Company has been transferred from the San Joaquin Valley division to the Los Angeles Basin office of the company.

FANNY CARTER EDSON has moved from Tulsa, Oklahoma, to 1835 North Locust Street, Denton, Texas.

The Fort Worth Geological Society, Fort Worth, Texas, has elected these officers for 1941: president, PAUL C. DEAN, consulting geologist and producer; vice-president, C. L. MOHR, Ambassador Oil Corporation; secretary-treasurer, WILLIAM J. HILSEWECK, Gulf Oil Corporation.

New officers of the Dallas Petroleum Geologists, Dallas, Texas, are: president, LEWIS W. MACNAUGHTON, consulting geologist; vice-president, J. A. LEWIS, Core Laboratories, Inc.; secretary-treasurer, FRED E. JOEKEL, Magnolia Petroleum Company.

H. W. STRALEY, III, of the department of geology, Baylor University, Waco, Texas, has returned after spending most of the summer in the Interior basins and the Appalachian Plateau for the Worthington Development Association.

The 1940 Reservoir Conditions Study Group of the Pacific Section of The American Association of Petroleum Geologists has compiled and abstracted more than 300 titles concerning "Reservoir Conditions and Mechanics." This bibliography has been mimeographed on 4- by 7-inch cards. Copies

may be obtained by members for 75 cents, postage prepaid, by addressing H. K. ARMSTRONG, 1002 Edison Building, Los Angeles, California. Only a limited supply is available.

W. P. COX, 1st Lieutenant, Field Artillery Reserves, formerly with the Western Gulf Oil Company, California, and the Mene Grande Oil Company, Venezuela, has been ordered to active duty with General Staff Corps, War Department, Washington, D. C.

MISS OLIVE C. POSTLEY, assistant geologist of the United States Geological Survey, died at Washington, D. C., January 14.

ROBERT L. CLARKE is employed on the geological staff of the Union Oil Company of California. He is stationed at Midland, Texas.

RICHARD E. KOCH, formerly at The Hague, has moved to Willemslaan 4, Batavia C, Java, D.E.I.

J. J. MULLANE and D. W. SEWELL, of the Carter Oil Company's research department, talked on "The Practice and Applications of Pressure Coring," before the Tulsa Geological Society, Tulsa, Oklahoma, January 20.

The Society of Economic Paleontologists and Mineralogists has elected the following officers by mailed ballot, to be effective immediately following the fifteenth annual meeting of the Society at Houston, Texas, April 2–3, 1941: president, HENRY V. HOWE, School of Geology, Louisiana State University, Baton Rouge; vice-president, ALVA CHRISTINE ELLISOR, Humble Oil and Refining Company, Houston, Texas; secretary-treasurer, HENRYK B. STENZEL (re-elected), Bureau of Economic Geology, Austin, Texas. The current officers are: president, CAREY CRONEIS, University of Chicago; vice-president, JOHN R. SANDIDGE, Magnolia Petroleum Company, San Antonio, Texas; secretary-treasurer, HENRYK B. STENZEL, Austin, Texas. NORMAN D. NEWELL, University of Wisconsin, Madison, is editor of the *Journal of Paleontology* and W. H. TWENHOFEL, University of Wisconsin, is editor of the *Journal of Sedimentary Petrology*. The Society, a Technical Division of the American Association of Petroleum Geologists, has 338 members.

JOHN L. P. CAMPBELL is working for the Lane-Wells Company, on radioactivity in well logging. His address is 1551 Lombardy Street, Houston, Texas.

J. HARLAN JOHNSON spoke on "The Terlinque District, Texas (Big Bend Area)," before the Rocky Mountain Association of Petroleum Geologists, January 20, at Denver, Colorado.

T. E. WEIRICH, of the Phillips Petroleum Company, Bartlesville, Oklahoma, discussed "Comparative Geology of the Cincinnati Uplift," before the Shreveport Geological Society, Shreveport, Louisiana, January 16.

H. B. STENZEL, geologist of the University of Texas Bureau of Economic Geology, talked on "Surface Relations of the Carrizo Sand" before the Houston, Texas, Geological Society, January 23.

The department of geology of the University of California at Los Angeles has secured the library of the late RALPH D. REED, one-time president of the A.A.P.G. This was secured from Mrs. Mary Reed through funds generously donated by various oil companies in California and several individuals. The library is combined with the geology department library, all of which is now officially known as the Ralph D. Reed Library. Recently several oil companies and individual geologists have enhanced the value of the library by donating books and runs of technical and trade journals, many of which are still needed! Friends of Dr. Reed or others interested in this project can still assist in building up this working petroleum geology library by offering duplicate or unused literature. Dr. Cordell Durrell is in immediate charge of the library. It is available for use by members of the A.A.P.G.

B. H. VAN DER LINDEN arrived in the United States from The Hague' Netherlands, on December 3. His temporary address is 39th floor, 50 West 50th Street, New York City.

The Shawnee Geological Society, Shawnee, Oklahoma, has elected new officers: president, M. C. ROBERTS of The Texas Company; vice-president, ROBERT L. CASSINGHAM of the Amerada Petroleum Corporation; secretary-treasurer, M. D. HUBLEY of the Stanolind Oil and Gas Company.

R. W. HARRIS, associate professor of micropaleontology at the University of Oklahoma, Norman, presented a paper on the Simpson formation before the Ardmore Geological Society, December 2.

A new organization, the Kentucky Geological Society, recently elected officers: A. C. MCFARLAN, department of geology, University of Kentucky, Lexington; vice-president, R. E. STOUDER, Louisville Gas and Electric Company, Louisville; secretary-treasurer, COLEMAN D. HUNTER, Kentucky-West Virginia Gas Company, Ashland.

FRED E. WOOD, petroleum engineer, has been appointed assistant to A. W. PEAKE, vice-president of the Standard Oil Company (Indiana), at Chicago, Illinois.

M. T. HALBOUTY, consulting geologist and petroleum engineer, Houston, Texas, talked before the South Louisiana Geological Society at Lake Charles, December 17, on "Oil and Gas Stratigraphic Reservoirs in the University Field, East Baton Rouge Parish, Louisiana."

The West Texas Geological Society, Midland, Texas, has elected officers for the year: president, ROBERT E. KING, Shell Oil Company, Inc.; vice-president, FRED F. KOTYZA, Tide Water Associated Oil Company; secretary-treasurer, WALTER G. MOXEY, Stanolind Oil and Gas Company.

New officers of the Michigan Geological Society are: president, JED B. MAEBIUS, Gulf Refining Company, Saginaw, Michigan; vice-president, LEE C. LAMAR, Carter Oil Company, Saginaw; secretary-treasurer, JUSTIN ZINN, Michigan State College, East Lansing; business manager, LEE C. MILLER, State proration officer, Lansing.

The Ardmore Geological Society, Ardmore, Oklahoma, has elected officers for the year: president, C. W. TOMLINSON, Simpson Building; vice-president,

TOM L. COLEMAN, United States Geological Survey; secretary-treasurer, BOB HANCOCK, Magnolia Petroleum Company, Box 299. Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

New officers of the South Louisiana Geological Society, Lake Charles, are: president, W. R. CANADA, Stanolind Oil and Gas Company; vice-president, P. H. JENNINGS, Magnolia Petroleum Company; secretary, E. M. BAYSINGER, Box 210; treasurer, BAKER HOSKINS, Shell Oil Company, Inc. The society meets on every third Tuesday of the month, at 7:00 P.M., at the Majestic Hotel. On January 21, C. D. LOCKWOOD, of Houston, talked before the society on "Oil and the War."

PERMIAN PARLEY AT HOUSTON

RONALD K. DEFORD, editor of the Permian volume, announces that on Tuesday, April 1, from 8 A.M. until noon, a general parley of members of the regional Permian stratigraphic committees and others interested in the progress of work on the Permian volume will be held in the Pine Room of the Rice Hotel, Houston, Texas. Penciled sections of the committees will be exhibited in this room during the Association's 26th annual meeting, April 1–4, for the convenience of stratigraphic workers and others in discussing problems of local and interregional correlation. The Pine Room will be devoted to Permian business throughout the meeting. The program at Houston will group papers on the paleontology of Permian formations and associated rocks. Some of these are preliminary drafts of papers for the Permian volume. As they are designed for the professional geologist who is not necessarily a paleontologist, this part of the program at Houston should receive general interest.

PROFESSIONAL DIRECTORY

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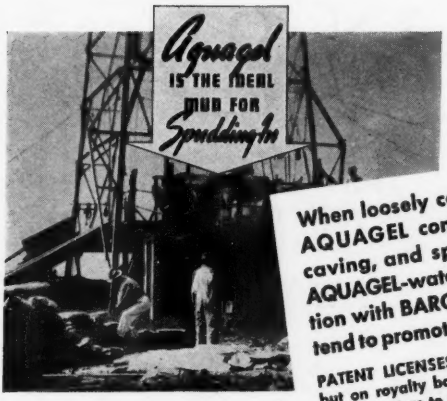

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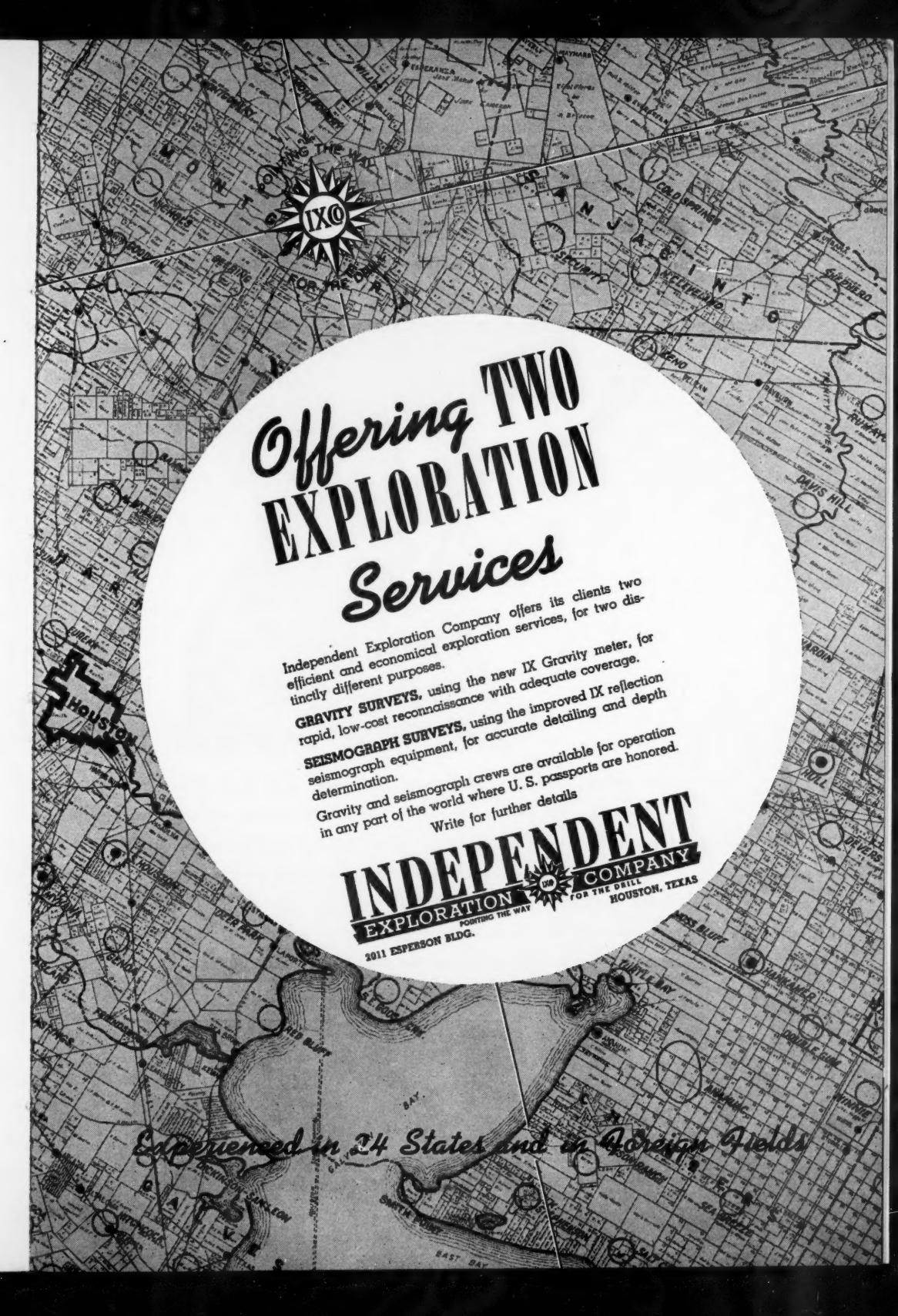

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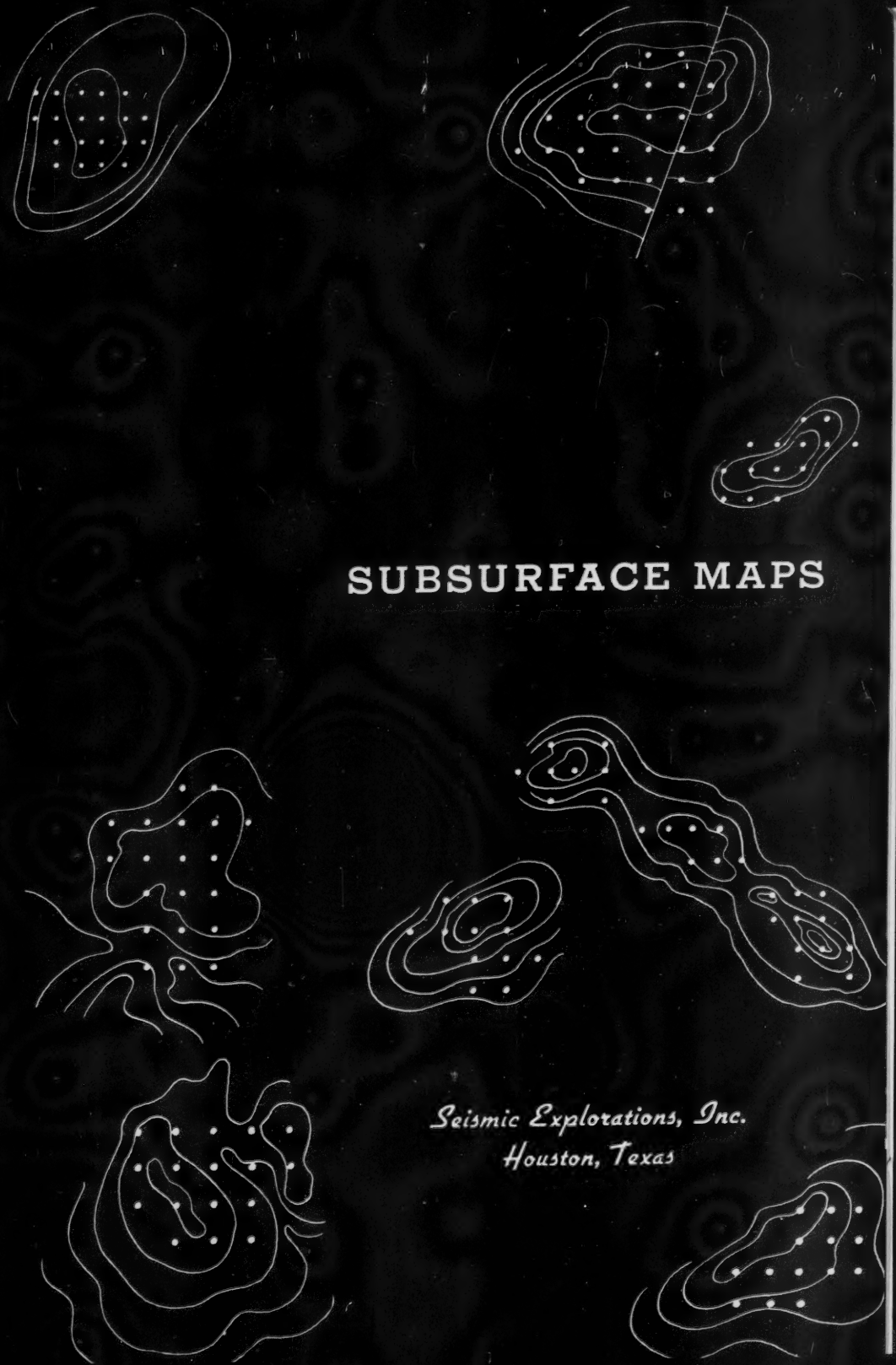

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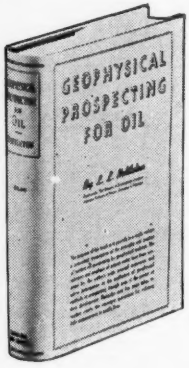

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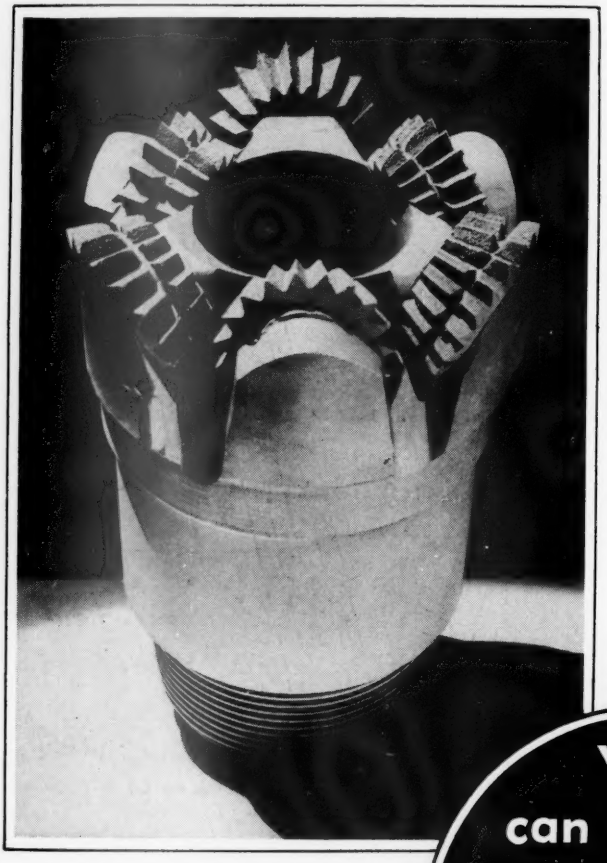

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